MONTHLY NOTICES

OF THE

ROYAL ASTRONOMICAL SOCIETY

Vol. 102 No. 2

1942 APRIL 10

ANNUAL GENERAL MEETING

Professor S. Chapman, President, in the Chair

The Minutes of the preceding Annual General Meeting were read and confirmed.

The following candidate was proposed for election as a Fellow of the Society, the name of the proposer from personal knowledge being appended:—

Albert Coleman, Warrant Officer I, Army Educational Corps, Queen Victoria School, Dunblane, Perthshire (proposed by F. J. Hargreaves).

The election by the Council of the following Fellows was duly confirmed:—

Vinicio Barocas, Royal Observatory (Greenwich), Cornerways, Abinger Hammer, Surrey; and
Rudolph M. Lippert, 3444 Landis Street, San Diego, California, U.S.A.

The President presented the Jackson-Gwilt Medal and gift to Dr. R. L. Waterfield, after delivering the following Address on the award:—

As previously announced the Council has awarded the Jackson-Gwilt medal to Dr. R. L. Waterfield for his general astronomical work.

This work is of three kinds, personal astronomical observation, the organization of astronomical observations, and astronomical history. His own observations are numerous and varied; he has been particularly active in the observation of eclipses, both solar and lunar, and it is therefore fitting that he is a member of the Joint Permanent Eclipse Committee. He has organized and carried out expeditions to five solar eclipses, at Giggleswick in 1927, the Rocky Mountains in 1930, New Hampshire in 1932, Chios in 1936, and in the Philippine Islands in 1939; he has thus obtained excellent results, particularly at Giggleswick, Chios and the Philippines. In 1932 he made photographic measurements of the relative surface brightness of the eclipsed part of the Moon and the uneclipsed full Moon, both in the photographic region of the spectrum, and in the near

infra red; the differences thus found, at λ 4300, λ 8000 and λ 8500, were 10, 7·9 and 7·4 stellar magnitudes.

At Headley he has also set up a fine photographic equipment for the study of star fields and comets.

He is Director of the Mars Section of the British Astronomical Association, and has himself done much visual work on the surface features of that planet. Earlier, in 1917, he studied the rotation of Jupiter's fourth satellite, and found its period to be the same as that of its revolution.

His book *A Hundred Years of Astronomy* gives further evidence of his devotion to our science, and constitutes a valuable summary of its progress during the century beginning with Queen Victoria's accession.

Dr. Waterfield, who is a doctor in the popular sense of the word, is at present in the Army Medical Service, which for the time being reduces his opportunities of astronomical observation, and also, to our regret, makes it impossible for him to remain on the Council of the Society.

In presenting the Jackson-Gwilt medal to you on behalf of the Society, Dr. Waterfield, may I express the hope that you will regard it not only as a token of our appreciation of the services you have already rendered to astronomy, but also as an encouragement, if one were needed, to their resumption when peace again makes this possible.

The President then delivered his Address on "The Source of the Sun's Energy" (see p. 110).

After the delivery of the President's Address, visitors were requested to withdraw, and the Society proceeded to the formal business of the Meeting.

The Report of the Auditors was read (see p. 57).

The Treasurer dealt with some of the points raised by the auditors, and explained that the writing off of an amount of £156, 1s. 5d. from the value of the General Fund investments had been necessitated by the discovery by the accountants that a mistake had been made in the Balance Sheet for 1937, whereby the value of the Lindley Bequest had been included at the nominal value of the stock transferred (£1156, 1s. 5d.) instead of at the actual value of the bequest (£1000). The investments had thus been over-valued by this amount, and the figure had accordingly been rectified in this year's accounts.

It might reasonably be expected that War Damage Insurance would be considerably less during the current year, and it should be pointed out that last year's premiums were retrospective to 1939.

The actual amount received for contributions during 1941 was £1118 against £1124 in 1940.

A vote of thanks to the Auditors of the Treasurer's Accounts for 1941 was proposed and carried unanimously.

The Secretary read a list of contents of the Annual Report of the Council.

The President announced that the Council had invited Dr. Theodore Dunham, jun., to deliver the George Darwin Lecture in 1942. Dr. Dunham had accepted the invitation subject to conditions rendering it possible for him to be present in this country by October.

The President made the following announcement:—

I have much pleasure in announcing that the Council of the Society have recently invited the British Astronomical Association to make this building their home, and that the Council of the Association have accepted the invitation. The arrangement is in the first instance for the duration of the war or a period of two years, whichever is the longer. The Association will have the use of this room and the Council room for their meetings. Their library will be housed in the upper library of this building, and will be open to B.A.A. members at times and under conditions similar to those that now obtain at Sion College. It is believed that this degree of use of our premises by the Association will not be in any way detrimental to the interests and convenience of Fellows. The Association will make a contribution to cover expenses reasonably incidental to their use of these premises, so that the arrangement will not throw any financial burden on the Society. It is confidently hoped that this arrangement will be beneficial to the interests of British astronomy, which both the Society and the Association have served so well in their different ways. The individuality and independence of the Association will in no way be affected or limited by this arrangement.

Those who have long felt an affection for this building as the home and centre of British astronomy will, I feel sure, rejoice that in future it will have this character even more fully, as the gathering place of all who serve our science, whether as amateur or professional.

The President further announced that the executive offices of the Society would be brought back from Oxford to Burlington House before the date of the next Ordinary Meeting (May 8).

It was proposed and carried that the Report of the Council be received and adopted, and that it be printed and circulated in the usual manner, together with the Report of the Auditors and the President's Address.

The President having appointed the Scrutineers, the Society proceeded to the ballot for Officers and Council for the ensuing year. The names of those elected are given on p. 131.

The thanks of the Society were given to the retiring Vice-President (Professor Plummer) and other retiring members of Council.

The thanks of the Meeting were given to the Scrutineers of the ballot.

The Meeting then adjourned.

REPORT OF THE COUNCIL TO THE HUNDRED AND TWENTY-SECOND ANNUAL GENERAL MEETING OF THE SOCIETY

1. *Introduction.*—Bye-law 37 provides that "The Council shall draw up a report on the state of the affairs of the Society, to be presented at the Annual General Meeting." For many years the Report has consisted of a table of membership statistics, the Treasurer's Accounts, and particulars of the Society's publications, celestial photographs and instruments; the "Report" issue of *Monthly Notices* contained also Obituary Notices of deceased Fellows and Associates, the Proceedings of Observatories and "Council Notes on the Progress of Astronomy," none of which can strictly be included in the Report of the Council. This plan did not give Fellows any general view of the state and activities of the Society during the Report year. To gain such a view it would have been necessary to refer to the Reports of Meetings in the *Monthly Notices*, and to examine the Council minutes, which, though open to inspection by any Fellow (bye-law 84), can be seen only at the Society's office.

The Council has therefore decided to give a narrative account of the state and activities of the Society during each calendar year; this, together with the table of membership statistics and the Treasurer's Accounts, will constitute the Council Report.

2. *Bye-laws.*—At the Special General Meeting of 1939 November 10 the Society adopted a new bye-law (87) and added to bye-laws 26 and 41. Bye-law 87 enabled the Council to suspend or abrogate any then existing bye-law, as found necessary or desirable, at any time when during the present emergency the normal procedure of calling a Special General Meeting is impracticable. Bye-law 26A allowed any Fellow on Active Service with H.M. Forces to be excused from payment of his Annual Contribution (until the end of the year in which peace is declared) without forfeiting his Fellowship; the Society's publications are not supplied to Fellows who signify their wish to avail themselves of this bye-law. Bye-law 41A expressly authorized a change in the hour of commencement of the Ordinary Meetings of the Society.

At the Annual General Meeting on 1941 March 14 the retiring President, Professor H. C. Plummer, made a short statement on the action taken by the Council up to that date, under these special powers. The customary months and times of meeting (Ordinary and Annual) had been altered; and to avoid undue delay, candidates for Fellowship proposed in 1940 November were definitely elected by the Council in February, without the confirmation of the Fellows at an Ordinary Meeting. Further, the Council suspended the operation of bye-law 26 (which enjoins the removal from the List of Fellows of those whose subscriptions are two or more years in arrear) in cases where subscriptions are "unobtainable under war conditions," owing, for example, to residence in enemy or enemy-occupied countries, or to difficulties of postal communication. The subscriptions of such "non-active" Fellows, among whom were numbered those provided for by bye-law 26A, were credited to a Suspense Account; this was shown on the Assets side of the Balance Sheet, but was not reckoned as an asset. The position of these Fellows will have to be reviewed at the end of the war, according to then prevailing circumstances.

Since 1941 March the main additional exercise of bye-law 87 has been to suspend bye-law 64, which involved undue delay at Council Meetings, and is out of accord with the practice of most scientific societies. The Treasurer now pays ordinary bills exceeding five pounds without the express order of Council; the President's signature

is added (not necessarily at a Council Meeting) only in the case of bills of exceptional amount; these are entered as "special bills" in the list of bills for payment circulated to Council members before each Meeting.

3. *General.*—The Society has so far been able to maintain most of its activities throughout the war, despite air-raid damage in 1941 May. Meetings during the summer months have been substituted for the mid-winter Meetings, such as are held in peace-time. The attendance at Meetings of the Society and the Council has been good. The Society has continued its publications, though on a somewhat reduced scale. The number of "active" Fellows has declined, but not seriously.

4. *Membership.*—The Council record with regret the death of the Society's one Honorary Member (Miss Annie J. Cannon), one Associate (Friedrich Wilhelm Hans Ludendorff), and of seventeen Fellows, as under; their deaths occurred in 1941 except where an earlier year is indicated. Obituary Notices are given on pp. 63–79, together with notices of G. W. Cook and R. E. Emden (Associate) held over from last year.

*Thomas Preston Battersby
*John Anderton Greenwood
Idwal Owen Griffith
John James Hall
*Edward Lindsay Ince
Charles William Jeffries
*John Mitchell
Daniel Walter Morehouse
Rudolph Moritz (1940)
*James Nangle
*Charles Pendlebury
John Stanley Plaskett
Sallie Duffield Proctor-Smyth
*Arthur Riches
*Arthur Cyril Ridsdale
Mary, Lady Saltoun (1940)
Henry John Wilkins

* Had compounded for Life Fellowship.

A table giving detailed statistics of the membership of the Society on 1941 December 31 is given on p. 49.

5. *Meetings during 1941.*—The Annual General Meeting was held in March, and there were six Ordinary Meetings, monthly from April to October with the exception of August. Meetings generally began at $16^h\ 30^m$ instead of 17^h, and were timed to end at 18^h.

The average attendance was rather less than half the peace-time number. Despite rationing difficulties it proved possible to provide refreshments before each Meeting.

6. *Geophysical Activities.*—No Geophysical Discussion was held during the year, and no *Geophysical Supplement* was published; three geophysical papers were received during the year, and will be published in a forthcoming *Geophysical Supplement.*

7. *George Darwin Lecture.*—No George Darwin Lecture was given during the year.

8. *Awards.*—In 1941, as in 1940, the Council decided not to award the Gold Medal. At its Meeting on 1941 December 12 the Council decided to award the Jackson-Gwilt Medal and Gift to Dr. R. L. Waterfield (see p. 41).

9. *Finance.*—The Treasurer's Accounts are presented in substantially the usual form, but contain some special war-time items. One is the Suspense Account already mentioned in § 2; others are payments for fire-watching, a rent allowance for the Assistant Secretary, and a travelling allowance for the porter. The most important war-time item, however, is the War Damage Insurance Contribution; the premiums paid relate to two different valuations of the Society's property; after the first payment, made on the basis of the pre-war valuation, the list of property to be insured was closely examined and the valuation was reduced slightly to its present figure of £14,000.

In 1941 the Council decided to have the Accounts examined by a firm of professional accountants; on their advice some changes have been made in the form of the Accounts, and some improvements in the Society's accounting system.

The Accounts have as usual been audited by two Fellows, whose report is given on p. 57.

10. *Publications.*—During 1941 the Society published *Monthly Notices*, vol. **101**, *Memoirs*, vol. 66, Part II, and *Occasional Notes*, No. 9.

By resolution of the Council the article by the President (Professor S. Chapman) on Edmond Halley, published in *Occasional Notes*, No. 9, was reprinted for general sale.

A new *List of Fellows* would normally have been published to replace the 1939 issue, but this was not done, because of paper shortage and the constantly changing or uncertain addresses of Fellows.

For many years each volume of *Monthly Notices* contained nine numbers, of which eight were associated with the eight Meetings of the session; this extended from winter to summer, and thus overlapped two calendar years. The war-time change of the session to the middle of the year gave the opportunity to associate the volume with one calendar year; it is intended to continue this practice. Thus vol. **101** refers to the year 1941, and contains papers received before the end of that year. It includes eight numbers, not specially associated with the Meetings held, so that no month is named on them. The date of receipt of each paper printed is indicated.

The *Memoir* issued during the year contains the full discussion by Dr. H. Spencer Jones of the Determination of the Solar Parallax from the Observations of Eros.

The number of papers submitted for publication by the Society has naturally decreased. The Society's main publication, *Monthly Notices*, totalled 391 pages during the year as compared with 702 in 1940 and 746 in 1939. But the reduction in the number of pages was partly offset by the use, in vol. **101** of the *Monthly Notices*, of smaller type and a larger type area. A great economy of paper was thus achieved, without a serious decrease in legibility.

The shortage of paper became intensified as the year progressed.

11. *Exchange of Publications.*—The Society continued to receive some foreign publications in exchange for its own, but in the case of many countries nothing was received and nothing could be sent. The "American Committee for the Continued Distribution of Astronomical Literature" (of which Dr. Bart J. Bok is chairman) kindly offered its services as intermediary for the exchange of the Society's publications where possible. The Council gratefully accepted the offer, and also had the assistance of some other intermediaries. In June and December such exchanges became still more difficult through the extension of the war to include Russia, the United States and Japan.

12. *The Library.*—Since the office of the Society was removed to Oxford in 1939 September (§ 13), the use of the Library, either directly or by post, has been difficult and restricted, although the porter was on the premises at Burlington House during most of each week-day, so that Fellows could generally gain admittance to the Library.

The more rare and valuable books and records were removed to Oxford in 1939 September, and access to them is specially difficult.

Two lists of *Additions to the Library* (other than by exchange) were issued during 1941.

A list of those who have presented gifts to the Library, other than by exchange, is given on p. 48.

13. *The Society's Office and Staff.*—During 1941 the Society's office was housed at the University Observatory, Oxford, whither it had been transferred in 1939 September; the Society is deeply indebted to the University of Oxford and to the Savilian Professor of Astronomy (Professor H. H. Plaskett) for this hospitality.

The office work was undertaken by the Assistant Secretary (Miss K. Williams) without the aid of the Clerk (Miss E. Wadsworth), who, however, though temporarily on leave from the service of the Society, gave occasional assistance at the Society's premises in London.

14. *The Society's Premises.*—The duties of porter and caretakers of the Society's premises have continued to be undertaken by Mr. and Mrs. R. J. Steel, who, however, ceased to reside there from 1941 October 15. On this account a volunteer team of Fellows was recruited for fire-watching on the premises at night and at the week-ends; the Society is much indebted to the Fellows who served in this way for several months. Later in the year this work was taken over by a team of fire-watchers and fire-fighters organized by the Royal Society in co-operation with the other Societies in Burlington House.

In May heavy air-raids in the vicinity damaged the Society's premises by blast, but fortunately the destruction was confined to broken windows and plaster; though the rooms were littered with broken glass and dirt, little permanent damage was done, and the premises were soon cleared by the loyal efforts of the porter and his helpers. The Office of Works was very helpful in making temporary repairs to the windows without delay.

15. *The Society's Movable Property and Instruments.*—In 1939 a strong-room was constructed in the basement of the Society's premises; it has been used to store some valuable pictures and other property that could not be conveniently moved to Oxford with the rarer books and irreplaceable records (§ 12). In 1941 the Society's stock of publications, normally stored in the basement of Burlington House, was partly dispersed by removal of some of them to the University Observatory at Oxford and the Solar Physics Observatory, Cambridge, by kind permission of the Directors (Professor H. H. Plasket and Professor F. J. M. Stratton).

16. *The Observatory.*—In 1941 the Council made an agreement with the Editors of *The Observatory*, by which each Fellow was supplied free with the six 1941 issues of the magazine. Thus every Fellow received the reports of the Society's Meetings, which have been a distinctive feature of *The Observatory*. The Editors also co-operated with the Secretaries by including in the magazine announcements and notices for the benefit of Fellows. The Society paid £100 as a block subscription on behalf of all the Fellows.

The agreement with the Editors, which is for a period of two years in the first instance, included an understanding that the Secretaries would give what assistance they could in obtaining astronomical articles for *The Observatory*, such as in normal times would have been published in *Occasional Notes*. The issue of the latter is temporarily suspended, probably for the duration of the war.

17. *The British Astronomical Association.*—In 1941 December the Council invited the British Astronomical Association to participate in a joint committee to discuss the transfer of the Association's Meetings and Library to the Society's premises; the Association accepted this invitation. (See also p. 43.)

18. *The London Mathematical Society.*—During 1941 the London Mathematical Society, which in pre-war years held its meetings on the Society's premises, continued to meet out of London.

19. *Proceedings of Observatories.*—In 1940 the Council did not invite observatories to report on their work during that year. In 1941 the observatories that had contributed such reports in past years were invited (where possible) to supply information appropriate for inclusion in a narrative account of British astronomical work during 1940 and 1941. Later it was decided to publish the individual reports (pp. 80–95) as sent in.

20. *Reports on the Progress of Astronomy.*—This issue of *Monthly Notices* contains, as in past years, several reports on astronomical progress. A report from Kodaikanal Observatory on Solar Prominences, intended for this issue, has not been received.

21. *Lists of Exchanges, Instruments, etc.*—These have been omitted from the Report. No celestial photographs have been added to the Society's collection during the year, and it is proving impossible to replenish the stock of slides for sale.

LIST OF PUBLIC INSTITUTIONS AND OF PERSONS WHO HAVE PRESENTED GIFTS TO THE LIBRARY DURING THE YEAR 1941

Baltic Geodetic Commission, Helsingfors
Committee for the Continued Distribution of Astronomical Literature, Harvard College Observatory
Griffith Observatory, Los Angeles
Maria Mitchell Association, Nantucket
New York Academy of Sciences
Editors of *The Observatory*

D. Carder Davies, Esq.
Dr. A. K. Das
Mr. M. A. Ellison
Dr. W. J. Luyten
Dr. A. Michailov
Mr. B. G. Narayan
Rev. I. Puig, S.J.
Mons. C. L. Sagui
Mons. Louis Sauty
Prof. T. J. J. See
Mr. P. C. Sengupta
Prof. W. M. Smart
Dr. L. J. Spencer
Dr. H. T. Stetson
Mr. H. R. Woltjer

In addition, the Society exchanges publications with about 250 institutions and observatories in most countries of the world; a full list of these is omitted, as in many cases difficulties of communication have led to suspension of exchange for the duration of the war.

PROGRESS AND PRESENT STATE OF THE SOCIETY

	Patron	Institutional Members	Honorary Member	Fellows			Associates	Total
				Compounders	Annual Subscribers	Non-active Fellows		
1940 December 31	1	5	1	182	625	25 *	49	888 *
Since elected	...	...	...	...	+15	...	...	...
Deceased, 1941	...	...	−1	−8	− 7	...	−1	...
Deceased 1940, death not notified	...	...	...	...	− 2	...	...	...
Resigned...	...	...	...	...	− 5	...	...	...
Since compounded	...	...	...	+3	− 3	...	...	...
Transferred to Suspense Account in 1941:								
(*a*) Subns. unobtainable under war conditions	...	...	...	...	−28	+28	...	...
(*b*) On Active Service (Bye-law 26A)	...	...	...	...	− 6	+ 6	...	...
Removed from list	...	...	...	...	− 6	...	...	...
1941 December 31	1	5	...	177	583	59	48	873

(Seven Associates are also Fellows, and are therefore counted twice in the above table.)

* *Erratum*

In the Table of Progress and Present State for 1940, the non-active Fellows were deducted from the number of annual subscribers, but their transference to a separate column was accidentally omitted. Thus the total shown in the final column should have been 888 instead of 863.

RECEIVED

	£ s. d.	£ s. d.
Balances, 1941 January 1:—		
In hand of Assistant Secretary, on Petty Cash Account	11 18 5	
At Westminster Bank, on Current Account	428 2 6	
At Westminster Bank, on "B" Account—		
Cash Balance of Spencer Bequest £410 18 11		
A. S. Williams Legacy 302 10 0		
	713 8 11	
At Westminster Bank, on "C" Account—		
Trust Funds £344 2 5		
Sales of Duplicate Books Fund 63 9 9		
Goodridge Bequest 5 3 0		
	412 15 2	
At Post Office Savings Bank £507 5 10		
At London Savings Bank 505 13 6		
	1012 19 4	
		2579 4 4
Dividends on Investments (as per schedule)	591 17 7	
Interest on Savings Banks deposits	51 10 3	
Income Tax refunded: 1940 April–December £140 9 8		
1941 January–April 98 9 1		
	238 18 9	
Sales of Publications:—		
For 1941 £153 7 4		
Due in 1939 0 7 3		
Due in 1940 5 7 5		
1942 in advance 11 15 6		
	170 17 6	
Reprints:—		
For 1941 £13 3 0		
Due in 1940 1 13 7		
	14 16 7	
Sales of Photographs	7 15 8	
Miscellaneous Receipts:—		
London Mathematical Society, Expenses of Meetings £6 0 0		
Assistant Secretary and Clerk, Pension Contributions 19 5 0		
Excess on Subscriptions 0 13 10		
Postages repaid 0 18 8		
	26 17 6	
		1102 13 10
Porter's Pension Contributions, to 1941 July 31		7 15 0
Franklin-Adams Charts		33 13 10
Received on Account of Subscriptions:—		
501½ Annual Contributions, 1941	1053 3 0	
5 Institutional Membership Fees, 1941	10 10 0	
1 ditto, 1942, in advance	2 2 0	
18 Annual Contributions, 1942, in advance	37 16 0	
1 ditto, 1943, in advance	2 2 0	
14 Admission Fees, 1941	29 8 0	
14 First Contributions, 1941	29 8 0	
Arrears paid off—		
1 for 1937 £2 2 0		
7 for 1939 14 14 0		
43 for 1940 90 6 0		
1 Institutional Membership Fee, 1940 2 2 0		
1 Admission Fee and First Contribution, 1940 4 4 0		
	113 8 0	
		1277 17 0
Compositions—		
1 Initial	31 10 0	
2 Reduced	10 10 0	
		42 0 0
"B" Account—		
Redemption of £1250 Metropolitan Consolidated 3% Stock, 1941		1250 0 0
"C" Account—		
Dividends on Investments (as per schedule)	159 5 8	
Income Tax refunded: 1940, April–December £30 0 11		
1941, January–April 3 17 4		
	33 18 3	
		193 3 11
		£6486 7 11

ASTRONOMICAL SOCIETY, FROM 1941 JANUARY 1 TO DECEMBER 31

Account

PAID

	£ s. d.	£ s. d.
Assistant Secretary: Salary £238 18 10		
Inland Revenue, Income Tax on ditto 31 1 2		
	270 0 0	
Assistant Secretary: Rent, etc.	107 0 0	
Clerk: Bonus (including balance of salary for 1940 December)	6 4 2	
Assistant Secretary: Work for London Mathematical Society in 1940	5 0 0	
Pension Premiums for Assistant Secretary and Clerk	57 15 0	
Porter and Wife: Wages	158 12 6	
Health and Unemployment Insurance	8 6 4	
		612 18 0
Insurance (general), Water Rate and Telephone	44 7 11	
War Damage Insurance £272 19 0		
Less paid from Spencer Bequest 23 19 7		
	248 10 5	
		292 18 4
Postage and Packing—		
Monthly Notices, etc.	47 9 10	
Office Postages	50 15 10	
		98 5 8
Printing, etc. (paid from General Account)—		
Monthly Notices (Vol. 101, Nos. 1–4)	400 17 0	
Geophysical Supplements (Vol. 5, No. 1)	44 2 4	
Reprints	28 7 3	
Miscellaneous	15 16 11	
Photo-engraving	13 18 11	
		503 2 5
A.R.P. Expenditure (other than War Damage Insurance)	93 15 1	
Stationery and Office Expenses	13 14 1	
Heating and Lighting	44 4 7	
Fittings and Repairs	3 16 10	
House Expenses and Laundry	13 6 6	
Accountant's Fee	5 5 0	
Subscription to Committee on Library Co-operation	1 1 0	
Honorarium to Mr Ryves for Report on Stanley Williams MSS.	10 10 0	
Authorised Travelling Expenses	69 18 2	
Clerical Assistance	5 16 0	
Expenses of R.A.S. Meetings and Committees	8 15 4	
Miscellaneous Expenditure	9 11 7	
Bank Charges and Cheque Books	2 1 11	
Purchase of Book from Potter Fund	0 7 6	
Block Subscription to *The Observatory* (1st instalment)	50 0 0	
Hire of Cinematograph	1 10 0	
		333 13 7
		1840 18 0
Expenditure from Spencer Bequest:—		
Printing, etc.—		
Monthly Notices (Vol. 101, No. 5/6, with postage) £123 11 10		
Occasional Notes (No. 9) 93 3 2		
Reprint of *Halley* article from *O.N.*, No. 9 ... ... 18 1 6		
Memoirs (Vol. 66, Pt. 2) 102 2 10		
	336 19 4	
Block Subscription to *The Observatory* (2nd instalment)	50 0 0	
Contribution to cost of War Damage Insurance	23 19 7	
		410 18 11
Purchase of £500 National Defence Bonds 2½ %, 1946/48	... ...	500 0 0
Expenditure on Franklin-Adams Charts	... ...	1 4 3
Expenditure on Trust Accounts—		
Turner and Horrocks Fund (Library)	4 17 10	
Harry Watson Fund (Library)	7 19 3	
		12 17 1
Balances, 1941 December 31—		
In hand of Assistant Secretary on Petty Cash Account	3 18 4	
At Westminster Bank, on Current Account, as per Pass Book £512 0 1		
Less cheques not yet presented 5 10 4		
	506 9 9	
At Westminster Bank, on "B" Account (A. S. Williams Bequest)	52 10 0	
At Westminster Bank, on "C" Account—		
Trust Funds £522 14 11		
Sales of Duplicate Books Fund 63 9 9		
Goodridge Bequest 6 17 4		
	593 2 0	
At Post Office Savings Bank	1029 6 10	
At London Savings Bank—		
Ordinary Department (including £250 A. S. Williams Bequest) £1021 16 0		
Special Investment Department 513 6 9		
	1535 2 9	
		3720 9 8
		£6486 7 11

Dr. *General Fund Revenue Account*

	£ s. d.	£ s. d.
To Salaries and Wages, including Allowance for Rent, Pension Premiums and National Insurance		613 18 10
,, Insurance, Water Rate and Telephone		48 17 2
,, War Damage Act, 1941, Part 2; Premiums paid to 1941 December 31	272 10 0	
Less Amount paid out of Spencer Bequest Funds	23 19 7	
		248 10 5
,, Printing, etc. (*including £100 reserve*), less amount paid out of Spencer Bequest Funds, £336, 19*s.* 4*d.*		603 2 5
,, Postage and Packing		98 5 8
,, *General Expenses* (*including reserves*)—		
Stationery and Office Expenses	15 14 1	
Lighting and Heating	47 4 7	
Travelling Expenses	69 18 2	
Block Subscription to *The Observatory*, less £50 paid out of Spencer Bequest Funds	50 0 0	
Clerical Assistance	5 16 0	
Honorarium for Report on Stanley Williams Manuscripts ...	10 10 0	
Subscription to Committee on Library Co-operation ...	1 1 0	
Accountants' Fee	21 0 0	
A.R.P. and Fire Watchers' Expenses	98 15 1	
Sundries	15 2 1	
	335 1 0	
Purchase of book from Potter Fund	0 7 6	
		335 8 6
,, Reserve for Repairs		40 0 0
,, Debts for Publications and Reprints, now proved unobtainable and written off		12 14 9
		2,000 17 9
,, Net Revenue one year to date transferred to Balance Sheet ...		267 6 1
		£2,268 3 10

One Year to 1941 *December* 31 — *Cr.*

		£	s.	d	
By *Amounts received from Fellows, viz.*—					
Annual Contributions		1,118	5	0	
Less Written off for Contributions credited in previous years but not received		90	6	0	
		1,027	19	0	
Add Amount previously written off but now received		2	2	0	
		1,030	1	0	
Admission Fees		29	8	0	
First Contributions		29	8	0	
Composition Fees—					
Initial Fee	£31 10 0				
Reduced Fees	10 10 0				
	42 0 0				
Less Transferred to Reserve Account	42 0 0				
	... ...				
Add Amount brought to Credit for the year	47 2 5				
		47	2	5	
					1,135 19 5
Note.—Fellows' 1941 *Contributions not received and included in Suspense Account in the Balance Sheet*—					
Unobtainable under War conditions	£88 4 0				
Waived under Bye-law 26A	31 10 0				
Others unpaid at 1941 December 31	130 4 0				
	£249 18 0				
,, Interest and Dividends received (gross)		867	13	4	
,, Interest on Bank Deposit Accounts received		51	10	3	
					919 3 7
,, Sales of Publications, Photographs and Miscellaneous Receipts for the year					213 0 10
					£2,268 3 10

Balance Sheet

LIABILITIES

	£ s. d.	£ s. d.
1 Contribution for 1942, paid in 1940	2 2 0	
18 Contributions for 1942, paid in 1941	37 16 0	
1 Contribution for 1943, paid in 1941	2 2 0	
1 Institutional Membership Fee for 1942, paid in 1941	2 2 0	
		44 2 0
Sundry Creditors for Accounts due but not presented		140 0 0
Reserve for Repairs and Maintenance		40 0 0
Cash Balances of Trust Funds	522 14 11	
Cash Balance of Goodridge Bequest	6 17 4	
		529 12 3
Trust Funds and Goodridge Bequest (Capital) as per contra		4,582 2 7
Income Tax on Trust Funds, 1941 April–December, not yet refunded		35 7 2
Special Fund (Capital) as per contra		1,480 2 2
Composition Fees Reserve Fund—		
As at 1940 December 31	743 7 5	
Received in 1941	42 0 0	
	785 7 5	
Less 6% transferred to Current Revenue	47 2 5	
		738 5 0
Franklin-Adams Charts—		
As at 1940 December 31	137 18 1	
Received in 1941	33 13 10	
	171 11 11	
Less Expenditure in Charts, 1941	1 4 3	
		170 7 8
Advance Receipts for Publications, 1942		11 15 6
Credits still in hand from 1939		1 7 1
General Fund—		
As at 1940 December 31	20,242 18 5	
Less Amount written off Book Value of Metropolitan Water Board 3% "B" Stock (*Lindley Bequest*)	156 1 5	
	20,086 17 0	
Add Excess on redemption of Metropolitan Consolidated 3% Stock	287 0 0	
	20,373 17 0	
Less Expenditure from Spencer Bequest	410 18 11	
	19,962 18 1	
Deduct Contributions taken as Assets in 1940 Balance Sheet, now transferred to Suspense Account:—		
9 for 1939 £18 18 0		
13½ for 1940 28 7 0		
1 Admission Fee and First Contribution, 1940 3 3 0		
	50 8 0	
	19,912 10 1	
Add Excess of Revenue over Expenditure, 1941	267 6 1	
	20,179 16 2	
Deduct 2 guineas over-credited in 1940 Accounts	2 2 0	
		20,177 14 2
		£27,950 15 7

To the Fellows of THE ROYAL ASTRONOMICAL SOCIETY.

We have examined the above Balance Sheet with the Books and Vouchers relating thereto and certify it to be correctly drawn up therefrom and in accordance with the information and explanations given to us.

1941 *December* 31

ASSETS

	£ s. d.	£ s. d.
Sundry Debtors, 1941	41 17 8	
Less Written off, considered irrecoverable under War conditions ...	36 15 10	
		5 1 10
Suspense Account, Fellows' Contributions, etc.—		
1 Admission Fee and First Contribution, 1940, unobtainable under War conditions	3 3 0	
2 Contributions, 1937–38, ditto	4 4 0	
13 ditto 1939, ditto	27 6 0	
26½ ditto 1940, ditto	55 13 0	
42 ditto 1941, ditto	88 4 0	
3 ditto 1939, waived under Bye-law 26A	6 6 0	
12 ditto 1940, ditto	25 4 0	
15 ditto 1941, ditto	31 10 0	
19 ditto 1940, unpaid at end of 1941 ... £39 18 0		
60½ ditto 1941, ditto 127 1 0		
1 Admission Fee and First Contribution, 1941, unpaid at end of 1941 ... ... 3 3 0		
	170 2 0	
	411 12 0	
Less 1 Contribution, 1940, written off under Bye-law 26A ...	2 2 0	
	£409 10 0	
Investments of General Fund as per 1940 Balance Sheet	£18,569 6 11	
Deduct Amount written off to reduce Stock included at nominal value	156 1 5	
Valued as at 1922 *December* 29 *or Subsequent Cost*	18,413 5 6	
Less £1,250 Metropolitan Consolidated 3% Stock redeemed £1,250 0 0		
Deduct Excess on Book Value 287 0 0		
	963 0 0	
	17,450 5 6	
Add Purchase of £500 National War Bonds 2½%, 1946–48, at cost	500 0 0	
		17,950 5 6
Investments of Special Fund, valued at cost		1,480 2 2
Investments of Trust Funds and Goodridge Bequest, valued as at 1922 December 29 or subsequent cost		4,582 2 7
Income Tax, 1941 April–December, deducted at source, not yet refunded—		
General Fund	177 6 8	
Trust Funds	35 7 2	
		212 13 10
Sundry Balances, as per Cash Account		3,720 9 8
		£27,950 15 7

We have verified the Securities representing the Investments and have found them to be in order.

SUFFOLK HOUSE,
5 LAURENCE POUNTNEY HILL, LONDON, E.C. 4,
1942 *January* 30.

SHARP, PARSONS & CO.,
Chartered Accountants.

INVESTMENTS

As at 1941 December 31

General Fund

£2000 Swansea Corporation 3½ per cent. Stock.
£2287, 6*s.* 9*d.* East Indian Railway 3 per cent. New Debenture Stock.*
£5125 London, Midland and Scottish Railway 4 per cent. Debenture Stock.*
£750 London, Midland and Scottish Railway 4 per cent. Preference Stock.*
£2400 Gas Light and Coke Co. 3 per cent. Consolidated Debenture Stock.*
£2000 Commercial Gas Co. 3 per cent. Debenture Stock.*
£496 Consolidated 4 per cent. Stock, 1967.
£500 Agricultural Mortgage Corporation, Ltd., 4½ per cent. Debenture Stock, 1961–91.*
£1000 Hull Corporation 4½ per cent. Redeemable Stock, 1952–72.
£1000 Central Electricity Board 4½ per cent. Stock, 1957–82.*
£700 Birmingham Corporation 3 per cent. Inscribed Stock, 1947.
£1807, 9*s.* 0*d.* War Loan 3½ per cent. Inscribed Stock.
£500 New South Wales 4 per cent. Stock, 1942–62.*
£1156, 1*s.* 5*d.* Metropolitan Water Board 3 per cent. "B" Stock.*
£500 National Defence Loan, 1954–58, 3 per cent. Bonds.*
£500 National War Bonds 2½ per cent., 1946–48.*

Grove-Hills Special Fund

£423, 15*s.* 11*d.* War Loan 3½ per cent. Inscribed Stock.
£695, 16*s.* 0*d.* Conversion Loan 3½ per cent., 1961.
£535 Agricultural Mortgage Corporation, Ltd., 4½ per cent. Debenture Stock, 1961–91.*

Trust Funds

£1212, 13*s.* 3*d.* East Indian Railway 3 per cent. New Debenture Stock.*
£542, 18*s.* 2*d.* India 3½ per cent. Stock.
£1004 Consolidated 4 per cent. Stock, 1967.
£965 Agricultural Mortgage Corporation, Ltd., 4½ per cent. Debenture Stock, 1961–91.*
£540, 10*s.* 4*d.* War Loan 3½ per cent. Inscribed Stock.
£1160, 16*s.* 3*d.* War Loan 3½ per cent. Inscribed Stock.

* *Taxed at source.*

REPORT OF THE AUDITORS FOR THE YEAR 1941

This year the Council decided, for the first time, to employ a firm of professional accountants to audit the Treasurer's accounts in full. The task of the auditors elected by the Society is, therefore, only to furnish a report of these accounts.

The Revenue Account shows an excess of income over expenditure of £267, 6*s.* 1*d.*, as compared with £365, 0*s.* 6*d.* last year. Owing to certain differences in the mode of presentation of the accounts these two figures are, however, not strictly comparable. Hitherto outstanding subscriptions due for the current year have been shown as assets, but this year all outstanding subscriptions have been entered in the Suspense Account. Further items of general expenditure amounting to £410, 18*s.* 11*d.* have been met, not from current income, but from the balance of the Spencer Bequest, which has thus been wound up in accordance with the terms of the bequest, which stipulated that the entire legacy must be spent within five years. Another change is that reserves for accounts due, but not yet presented, are this year included in each of the separate items of General Expenses in the Revenue Account, instead of being shown as a single item.

Examination of the Cash Account shows a total expenditure of about £2251 (including that from the Spencer Bequest), which is about £100 less than last year. This is to be attributed to a decrease in printing expenses of £414 and a decrease of £90 in expenditure on postage, but these two items are largely offset by War Damage Insurance Premiums amounting to £272, 10*s.* and a grant of £100 as a block subscription to *The Observatory* magazine, into which *Occasional Notes* is temporarily merged.

In addition to the War Damage Insurance Premiums, specific war expenditure has increased from £12, 13*s.* in 1940 to £93, 15*s.* 1*d.*, due mainly to the participation of the Society in the general scheme for the employment of professional fire-watchers at Burlington House.

As a precaution against war damage, part of the Society's stock of publications has been sent to Oxford and Cambridge. The Offices of the Society remain at the University Observatory, Oxford, and the Society's thanks are due to Professor Plaskett for this continued hospitality, and also for considerable storage facilities.

The Society's investments have been increased by the purchase of £500 National War Bonds, 2½ per cent. (1946–48), from the Cash Balance of the General Fund. An amount of £156, 1*s.* 5*d.* was written off from the investments of the General Fund, being the difference between the nominal value and the actual value (£1000) of the Lindley Bequest. £1250 Metropolitan Consolidated 3 per cent. Stock was redeemed at par during the year, and an amount of £287, being the profit on the original cost of the investment, has been added to the General Fund. With the concurrence of the accountants, there has been no revaluation of the Society's investments.

A list has been laid on the table containing the names of those Fellows who are still in arrear for sums due on 1941 January 1, with the amount due against each Fellow's name.

We have received from the Assistant Secretary all the information and explanations which we have required, and we gratefully acknowledge her valuable co-operation in this respect.

(Signed) DAVID S. EVANS
M. G. ADAM

1942 *March* 28.

GIFTS TO THE GENERAL FUNDS AND PROPERTY OF THE SOCIETY

The John Lee Gift : In 1836 John Lee, Esq., LL.D., gave the Advowson of the living of Hartwell ; in 1844 he gave the Advowson of the living of Stone, Bucks. In 1879 these Advowsons were repurchased by his heir, Edward Lee, Esq., for £700.

The Lawson Bequest (1856) : Henry Lawson, Esq., bequeathed to the Society the sum of £200, free of legacy duty.

The Carrington Bequest (1876) : R. C. Carrington, Esq., F.R.S., bequeathed to the Society £2000 Consols.

The Lambert Bequest (1877) : C. J. Lambert, Esq., presented to the Society the sum of £500, free of legacy duty, being part of a sum of money bequeathed by his father, Charles Lambert, Esq., for scientific purposes.

The McClean Bequest (1905) : Frank McClean, Esq., LL.D., F.R.S., bequeathed to the Society the sum of £2000, free of legacy duty.

The Farrar Bequest (1906) : The Rev. A. S. Farrar, D.D., bequeathed to the Society the sum of £100, free of legacy duty.

The Parsons Gift (1922) : The Hon. Sir Charles Parsons, K.C.B., F.R.S., gave to the Society £2500 War Stock 1929–47, in memory of his father, the 3rd Earl of Rosse, who made the 6-foot reflector, and who died 1867 October 31.

The Grove-Hills Bequest (1922) : Colonel E. H. Grove-Hills, C.M.G., F.R.S., bequeathed to the Society, free of legacy duty, his collection of early astronomical and mathematical books up to the year 1700, together with a sum of £250 to cover the expenses incurred by the Society in connection with the books.

The Lindemann Bequest (1931) : A. F. Lindemann, Esq., bequeathed to the Society the sum of £1000, free of legacy duty.

The Archdeacon Potter Bequest (1933) (*see below*).

The Goodridge Bequest (1936) (*see below*).

The Herbert Spencer Bequest (1936) (*see below*).

The Lindley Bequest (1937) : Miss Julia Lindley bequeathed to the Society the sum of £1000, free of legacy duty, which has been received from the Public Trustee in the form of £1156, 1*s.* 5*d.* Metropolitan Water Board 3 per cent. "B" Stock.

THE GROVE-HILLS SPECIAL FUND

In 1922 the Treasurer, Colonel Grove-Hills, collected by his private efforts, with the approval of the Council, a Special Fund to meet the immediate financial difficulties of the Society. The total amount received from all sources (including dividends on the investments representing the fund) has been £1913, 1*s.* 11*d.*, of which £1480, 2*s.* 10*d.* has been invested and is now represented by £535 Agricultural Mortgage 4½ per cent., £423, 15*s.* 11*d.* War Stock 3½ per cent., and £695, 16*s.* Conversion Loan 3½ per cent. 1961.

THE HERBERT SPENCER BEQUEST

Herbert Spencer, Esq., who died in 1903, nominated the Royal Astronomical Society as one of twelve Learned Societies to be eventual beneficiaries of his residuary estate. His estate was wound up in 1936, and the Society's share of the residue amounted to £1241. The conditions of acceptance of the legacy were that the sum received should be spent in certain specified ways by the Governing Body within five years of the date of payment, and might not be used in any way for purposes of endowment. The sum of £732, 11*s.* 9*d.* was temporarily invested in the purchase of £700 War Loan 3½ per cent. (the dividends being added to the value of the bequest), of which £200 stock was sold in 1938 to meet expenditure, £200 stock was similarly sold in 1939, and the remaining £300 stock in 1940. In 1941 the whole of the remaining cash balance has been expended.

Receipts and Expenditure, 1936–1941 *Dec.* 31

	£	*s.*	*d.*		£	*s.*	*d.*
1936. First instalment of Bequest received May 7	500	0	0	1936 Dec. Purchase of £500 War Loan 3½ per cent.	531	13	3
1936. Second instalment received July 20	400	0	0	1936. Expenditure as per 1936 Cash Account	276	10	7
1936. Final instalment received Nov. 4	341	0	0	1936 Dec. 31. Cash Balance at Bank, carried forward ...	432	16	2
	£1241	0	0		£1241	0	0

	£	*s.*	*d.*		£	*s.*	*d.*
1937 Jan. 1. Cash Balance at Bank, brought forward ...	432	16	2	1937. Purchase of £200 War Loan 3½ per cent.	200	18	6
1937. Dividends, War Loan 3½ per cent.	21	0	0	1937. Cash expenditure as per 1937 Cash Account	104	7	6
				1937 Dec. 31. Cash Balance at Bank, carried forward ...	148	10	2
	£453	16	2		£453	16	2

	£	*s.*	*d.*		£	*s.*	*d.*
1938 Jan. 1. Cash Balance at Bank, brought forward ...	148	10	2	1938. Purchase of Instruments ...	124	7	0
1938. Dividends, War Loan 3½ per cent.	24	10	0	1938. Shelving, etc. for Spencer Room	193	5	0
1938. Nov. Sale of £200 War Loan 3½ per cent.	198	11	6	1938 Dec. 31. Cash Balance at Bank, carried forward ...	53	19	8
	£371	11	8		£371	11	8

	£	*s.*	*d.*		£	*s.*	*d.*
1939 Jan. 1. Cash Balance at Bank, brought forward ...	53	19	8	1939. Purchase of Instruments ...	85	15	1
1939. Dividends, War Loan 3½ per cent.	17	10	0	1939. Carpet, etc., for Spencer Room	11	1	0
1939. Sale of £200 War Loan 3½ per cent.	181	11	6	1939 Dec. 31. Cash Balance at Bank, carried forward ...	163	18	11
1939. Refund from Office of Works on shelving for Spencer Room	7	11	3				
Interest on Deposit Account ...	0	2	7				
	£260	15	0		£260	15	0

	£ s. d.		£ s. d.
1940 Jan. 1. Cash Balance at Bank, brought forward ...	163 18 11	1940. Grant from Fund ...	50 0 0
1940. Sale of £300 War Loan 3½ per cent.	297 0 0	1940 Dec. 31. Cash Balance at Bank, on "B" Account ...	410 18 11
	£460 18 11		£460 18 11

	£ s. d.		£ s. d.
1941 Jan 1. Cash Balance at Bank, brought forward ...	410 18 11	1941. Printing (as per cash account)	336 19 4
		Half payment of block subscription to *The Observatory*	50 0 0
		Contribution to cost of War Damage Insurance	23 19 7
	£410 18 11		£410 18 11

THE ARCHDEACON POTTER FUND

The late Archdeacon Beresford Potter, who died 1931 May 10, bequeathed to the Society a 3/88th share of his residuary estate. This legacy was received in 1933, and now stands invested in £300 3½ per cent. War Stock, the cash balance of £17, 15*s.* 2*d.* being expended on the library in 1934. The Council resolved to allocate the dividends from this Fund for the purposes of the library.

	£ s. d.		£ s. d.
1941 Jan. 1. Balance of Fund ...	43 12 6	1941. Purchase of Books ...	0 7 6
1941. Dividends, War Stock 3½ per cent.	10 10 0	1941 Dec. 31. Balance of Fund	53 15 0
	£54 2 6		£54 2 6

THE GOODRIDGE BEQUEST

The Goodridge Bequest (1936): Captain J. J. L. Goodridge bequeathed to the Society the sum of £50, free of legacy duty. The bequest has been invested in £49, 0*s.* 4*d.* War Stock 3½ per cent.

	£ s. d.		£ s. d.
1941 Jan. 1. Balance of Fund ...	5 3 0	1941 Dec. 31. Balance of Fund	6 17 4
1941. Dividends, War Stock 3½ per cent.	1 14 4		
	£6 17 4		£6 17 4

TRUST FUNDS

The Turnor Fund and the Horrocks Memorial Fund: In 1853 the Rev. Charles Turnor, M.A., bequeathed a sum of £500, which now stands in £464, 18*s.* East Indian Railway 3 per cent. Debenture Stock. In 1876 the Society received a sum of £38, 15*s.*, the unexpended balance of a fund collected for the purpose of erecting a memorial in Westminster Abbey to Jeremiah Horrocks: to this the Society added the sum of £55, 15*s.*, and the whole now stands in £103, 6*s.* East Indian Railway 3 per cent. Debenture Stock. The interest on these funds is to be used in the purchase of books for the library.

	£ s. d.		£ s. d.
1941 Jan. 1. Balance of Fund ...	10 3 5	1941. Purchase of Books ...	4 17 10
1941. Dividends, East Indian Railway	8 16 9	1941 Dec. 31. Balance of Fund	21 7 5
Income Tax, 1940 April–1941 April, refunded	7 5 1		
	£26 5 3		£26 5 3

The Harry Watson Memorial Fund: In 1920 Mrs. Watson presented to the Society the sum of £300 as a memorial to her late husband, Lieut.-Col. Harry James Watson, F.R.A.S., the interest on this sum to be used for the purchase of books for the library, such books to be indicated by a special book-plate. This gift now stands invested in £542, 18*s.* 2*d.* India 3½ per cent. Stock. In 1923 Mrs. Watson bequeathed a further sum of £958, 17*s.* to the Society, which now stands invested in £965 Agricultural Mortgage 4½ per cent. Stock. The Council resolved that these two sums should together constitute a Trust Fund, to be designated *The Harry Watson Memorial Fund*, to be used for the purchase and binding of books.

	£	*s.*	*d.*		£	*s.*	*d.*
1941 Jan. 1. Balance of Fund	80	16	5	1941. Purchase of Books ...	7	19	3
1941. Dividends, India 3½ per cent.	19	0	0	1941 Dec. 31. Balance of Fund	132	0	7
Dividends, Agricultural Mortgage 4½ per cent.	21	14	4				
Income Tax, 1940 April–1941 April, refunded	18	9	1				
	£139	19	10		£139	19	10

The Lee and Janson Fund: In 1834 John Lee, Esq., LL.D., gave £100, and in 1876 T. C. Janson, Esq., bequeathed £200, the interest to be given to the widow or orphan of a deceased Fellow. These amounts now stand in £334, 10*s.* 9*d.* East Indian Railway 3 per cent. Debenture Stock.

	£	*s.*	*d.*		£	*s.*	*d.*
1941 Jan. 1. Balance of Fund ...	53	7	3	1941 Dec. 31. Balance of Fund	62	16	5
1941. Dividends, East Indian Railway	5	4	1				
Income Tax, 1940 April–1941 April, refunded	4	5	1				
	£62	16	5		£62	16	5

The Hannah Jackson (née Gwilt) Fund: In 1861 Mrs. Hannah Jackson (*née* Gwilt) gave £300 Consols, which now stands in £309, 18*s.* 6*d.* East Indian Railway 3 per cent. Debenture Stock; the interest to be given in medals or other awards in accordance with the terms of the Trust.

	£	*s.*	*d.*		£	*s.*	*d.*
1941 Jan. 1. Balance of Fund ...	26	16	8	1941 Dec. 31. Balance of Fund	35	12	2
1941. Dividends, East Indian Railway	4	16	6				
Income Tax, 1940 April–1941 April, refunded	3	19	0				
	£35	12	2		£35	12	2

The George Darwin Lectureship Fund: In 1926 Sir James Jeans presented to the Society the sum of £1000 for the endowment of an annual lectureship, to be called *The George Darwin Lectureship*, the lecture to be on some subject of interest to astronomers, preference being given, in electing a lecturer, to one normally resident outside the British Isles.

This sum now stands in £1004 Consolidated 4 per cent. Loan. The income is annually applied to the purposes of the Trust in accordance with the terms of the Deed of Gift.

	£	s.	d.		£	s.	d.
1941 Jan. 1. Balance of Fund ...	60	7	11	1941 Dec. 31. Balance of Fund	100	11	1
1941. Dividends, Consolidated 4 per cent. Loan	40	3	2				
	£100	11	1		£100	11	1

The A. G. Stillhamer Trust (1937): The late A. G. Stillhamer, Esq., F.R.A.S., of Bloomington, Illinois, left all his property outright to Miss Maude S. Capps, of Bloomington; but on account of certain personal memoranda and conversation between Mr. Stillhamer and Miss Capps, the latter resolved to carry out what she believed to have been Mr. Stillhamer's wishes by the payment to the Royal Astronomical Society of the sum of 2500 dollars in cash, the conditions of acceptance being that the principal is to remain intact in the endowment fund of the Society, and the income therefrom to be used annually to pay expenses of scientific research or to purchase definite scientific instruments for use in scientific instruction or research. The bequest has been invested in £491, 10*s*. War Stock 3½ per cent.

	£	s.	d.		£	s.	d.
1941 Jan. 1. Balance of Fund ...	51	12	0	1941 Dec. 31. Balance of Fund	68	16	0
1941. Dividends, War Stock 3½ per cent.	17	4	0				
	£68	16	0		£68	16	0

The E. W. Brown Trust (1939): Dr. E. W. Brown, of Yale University, who died in 1928, bequeathed to the Society the sum of five thousand dollars, and desired that the income from the bequest should be used for assistance in the calculation of accurate orbits of the bodies of the solar system, such income as should not be used for this purpose being used for the general purposes of the Society. The bequest was received in 1939 July, and was invested in £1160, 16*s*. 3*d*. War Stock 3½ per cent.

	£	s.	d.		£	s.	d.
1941 Jan. 1. Cash Balance of Fund	60	18	9	1941 Dec. 31. Balance of Fund	101	11	3
1941. Dividends, War Stock 3½ per cent.	40	12	6				
	£101	11	3		£101	11	3

OBITUARY NOTICES

THOMAS PRESTON BATTERSBY, Maj.-Gen., was elected a Fellow of the Society over sixty years ago on 1880 April 9, and at the time of his death on 1941 February 13 was in fact fifth senior Fellow.

Born in 1856 in Ireland, he had a distinguished military career. After passing through the Royal School, Armagh, and Woolwich, he became Lieutenant, Royal Artillery, in 1876, and later served for thirty-six years in the Army Ordnance Department. He rose to the post of Principal Ordnance Officer, retiring in 1918. He was created C.B. in 1917. After his retirement he lived for some years at his family home in Ireland, but moved to Farnham, Surrey, in 1940. Owing to the energy with which he threw himself into his professional duties he was only able to study astronomy privately, but he was deeply interested in the subject, and in many other branches of science, throughout his life. He read widely and published a number of literary works, including some contributions on general science.

He was married, and is survived by his widow. His only son was killed in 1914 while serving as Captain in the Royal Field Artillery.

GUSTAVUS WYNNE COOK * was born in Philadelphia on 1867 December 12, son of Richard Y. Cook, prominent banker and business man. He was educated at Eastbury Academy and later attended classes at the Franklin Institute. He followed his father in a business career, becoming president of the South Chester Tube Co. and of the South Chester Terminal and Warehouse Co., as well as a director of several banks and trust companies.

His interest in astronomy began when, as a boy, an elderly clergyman told him about the stars. During his life, despite his manifold activities—business, social and recreational—this enthusiastic interest continued, culminating in the creation of the Cook Observatory, where he built and designed instruments, made observations and guided the researches of his staff.

As a young man he installed a telescope on the roof of his Philadelphia home. Later he moved to Roslyn House, Wynnewood, where he built an observatory to contain an 8-inch refractor by Alvan Clark. In 1934 a 28·5-inch reflector, by J. W. Fecker, on which the 8-inch was mounted as a guiding telescope, was added. Next a 2-prism spectrograph, for attachment to the reflector, was secured. Dr. Orren Mohler was placed on the staff and obtained a very complete series of spectrograms of Nova Herculis, a discussion of which forms the Cook Observatory's first formal publication.

A 15-inch objective by Brashear was then purchased and mounted in a siderostat telescope with the original object of being devoted to visual observations. However, even this was destined to be employed for a considerable time in a programme which prevented its regular visual use. In April 1934 Dr. A. M. Skellett, of the Bell Telephone Laboratories, described a method of observing the solar corona without an eclipse, with the use of television technique. Dr. Cook extended to him the facilities of the observatory, and after several years of experimentation the corona was successfully observed with the siderostat telescope.

The Sun was one of Dr. Cook's chief interests, and he made possible the writer's expedition to two solar eclipses. At Wynnewood another building was erected, containing a 4-foot photoheliograph and a Hale spectrohelioscope, later adapted as a spectroheliograph.

* Notice held over from 1941.

Then an astrographic mounting was acquired, equipped with three Ross-Fecker lenses. This was employed in making a complete atlas of the Milky Way. It was intended eventually to move the instrument to a southern station, and the mounting was designed with this in view. The last instrument was a 10-inch Schmidt camera, which arrived shortly before Dr. Cook's death.

It was long Dr. Cook's intention to provide for the continuation of the observatory's work, so he bequeathed it to the University of Pennsylvania, whose Flower Observatory is located but a few miles away. Both are now operated as units of the University's Department of Astronomy, but it is intended that Dr. Cook's name shall be perpetuated in the observatory he founded.

He was elected a Fellow of the Royal Astronomical Society on 1932 June 10, and of the American Philosophical Society in 1934. He was a member of the American Astronomical Society, the American Association for the Advancement of Science, and many other organisations. In 1937 the University of Pennsylvania conferred upon him the degree of Doctor of Science, *honoris causa*.

In addition to astronomy, he had many other crafts at his finger-tips. He was an early experimenter with wireless; he was a finished artist, especially in water colour and ink drawing, and an expert photographer. He also made exquisitely beautiful models of ships. In his library he had gathered many literary treasures, including, for example, the original holograph of Kirchhoff's first announcement of his discovery of the principles of spectrum analysis, and one of three known copies of Anthony Askham's *A Lytel Treatise of Astronomy* (London, 1552), the first separate original book in English on an astronomical subject.

By nature extremely generous and hospitable, he was a charming host. A man of abundant energy and enthusiasm, he was well described in one account of his work as "One man who is having fun." About 1935 his health began to fail, and he was forced, much against his will, to give up many activities. He died at his home on 1940 June 4. He married Nannie Mumford Bright, of Williamsburg, Va., who survives him with two daughters and four grandchildren.

JAMES STOKLEY

JOHN ANDERTON GREENWOOD was born on 1864 January 16 at Morton, Bingley, Yorks, and died on 1941 July 2 at Funtington House, near Chichester, where he lived for forty-six years. He practised for a time as a solicitor, but later occupied himself largely with local Government; thus for many years he was a member of West Sussex County Council, and J.P. for Sussex, and from 1932 to 1941 Chairman of the County Bench at Chichester and Bognor Regis.

He had a general interest in astronomy during most of his life, illustrated by the fact that he was a member of the British Astronomical Association for just over fifty years from its inaugural year, 1890. For some time he had an equatorial telescope mounted in his garden, but he does not appear to have left published records of his observations.

He married twice. By his first marriage (with Phœbe Waldy, of Worsall Hall, Yorks, in 1892) he had one son and two daughters, one dying in infancy. But tragedy pursued the family; his son was accidentally killed in H.M.S. *Bellerophon* in 1912, and his sole grandchild was killed at Dunkirk in 1940.

He was elected a Fellow of the Society on 1896 November 13.

IDWAL OWAIN GRIFFITH was born in Caernarvonshire on 1880 September 23 and died on 1941 September 22. He was educated at Llandovery College and at Balliol College, Oxford, where he read mathematics followed by physics. After a distinguished undergraduate career he was elected to a Fellowship at St. John's College,

Oxford, and became demonstrator in the Clarendon Laboratory. In 1920 he became an Official Fellow of Brasenose College and then taught in the schools of both mathematics and physics. He did research on the measurement of temperature in the high-pressure arc and collaborated in *Photographic Photometry* (Clarendon Press, 1926). But it is as an administrator that his loss to the University is most particularly felt. He was Chairman of the Physical Sciences Board, Vice-Chairman of the General Board of the Faculties, and a member of the Hebdomadal Council. There he spoke with persuasion and authority of the varied needs of the physical sciences, reconciling them to the planning and spending departments of the University. In the last war he did distinguished service in the Royal Flying Corps on the scientific and experimental side and received the A.F.C. In this war he had done much work as Director of Studies in organizing technical courses for R.A.F. cadets.

His contribution to the technique of night flying, which he helped to develop towards the end of the last war, though too late to become operational, had doubtless some contacts with astronomy, but it is in *Photographic Photometry* that his work (here in association with Dr. G. M. B. Dobson and Dr. D. N. Harrison) has most astronomical interest. The problem considered was that of measuring the intensity of light by its effect on a photographic plate, chiefly through the device of the optical wedge. The details and difficulties that arise were reviewed both in the light of the experience of other workers in this field and from the authors' own application of the technique (*inter alia*) to the measurement of relative brightness across the Sun's disc and to the spectroscopic determination of the amount of ozone in the Earth's atmosphere. The result was a very practical handbook backed where possible by theoretical considerations.

Though military (and academic) experience had taught him when to resist, he showed in public affairs a sweet reasonableness and a patience that made him ideal as a chairman or a committee member. These qualities sprang from an unfailing kindness and from a natural habit of always thinking well of his fellow-creatures. His pupils owed much to this encouragement and to his insistence that they should give of their best: a long line of successes in the schools showed how admirable a teacher he was. His innumerable friends, too, throve in his genial presence; he was always at their service for help or encouragement, and his house and college rooms were the scene of much unostentatious hospitality.

He found his recreation at every opportunity on the golf-course, where he was no mean performer, and, in vacation, among the mountains whether of the continent or of his native Wales. He delighted too in good music, though he was inclined to think that good music mostly ceased with Brahms.

In 1909 he married Alice Godfrey Isaac (who survives him) and leaves one son, John, who, after a notable undergraduate career at New College, is now Classical Fellow of Jesus College, Oxford.

He was elected a Fellow of the Society on 1926 November 12.

T. W. CHAUNDY

JOHN JAMES HALL was born on 1845 December 11. One of the Society's oldest Fellows, he died at the age of ninety-six on 1941 January 15.

His long life was devoted mainly to horology, a science into which he poured all the energy and practical skill of an enthusiast. His name was widely known in horological circles not only for his contributions to *The Horological Journal*, *The English Mechanic*, *Watch and Clockmaker*, and other journals, but also for his active work on many clocks in Exeter and its surroundings. One of his best-known accomplishments was the restoration of a fourteenth-century clock in Exeter Cathedral, which was entrusted to him; his services were also called upon for the reconditioning or designing of turret clocks at Ottery St. Mary, Wimborne Minster and other west country churches. He had a special aptitude for devising safety mechanisms to meet special needs. "Some

Modern Advances in Turret Horoscopy", "The Normal Life of a Good Watch", "A Battery for an Electric Clock", "A Universal Joint of Simple Design"—such a selection of titles from his articles (numbering over 200 in all) indicate his natural bent.

His interest in the mechanics of clocks began early. Much of his training was due to James Padbury of Bishop's Waltham, whom he acknowledged as his "honoured master." The Padbury watch chronometer he presented to the Society and, until the outbreak of the present war, it was regularly placed on the President's table at meetings of the Society. Another of his gifts to the Society was the Arnold chronometer which was used in Professor Carroll's eclipse expedition to Siberia in 1936. These are only two instances of his passion for presenting for public use the clocks on which he had lavished his care in design or improvements. In 1931 he presented to the Exeter Public Library a new standard clock which incorporated over ten years' original work in design. The City Library also possesses a complete collection of his articles entitled *Fasces Exonienses*.

It was not only horological matters that absorbed his interests. As lay assistant he served and preached in many churches of the Devonshire countryside, in the Royal Devon Hospital and in numerous charitable institutions. Astronomy, as well as horology, used to form the subject of some of his lectures which stand as further proof of his public spiritedness. These varied activities were marked by extraordinary vitality and freshness of outlook which never waned in his ripening years.

He was elected a Fellow of the Society on 1899 February 10 and in subsequent years attended many meetings.

He married twice. Of two sons and two daughters by the first marriage all but one son are still living. His second wife, whom he married in 1924, late in life, also survives him.

EDWARD LINDSAY INCE * was born at Amblecote, Staffs, on 1891 November 30, the only son of Edward Ince, late of H.M. Customs and Excise. His early education was received at Criccieth School and the County School, Portmadoc; the family then removed to Scotland, and his secondary education was completed at Perth Academy, whence he proceeded to Edinburgh University in 1909 to read for honours in mathematics under Professor George Chrystal. Chrystal died in 1911, and it was under his successor that Ince graduated in 1913 with first-class honours. On graduation he was awarded a scholarship which enabled him to remain in Edinburgh for initiation into mathematical research.

After the 1914–18 war he held lectureships, first in Leeds, and from 1920 to 1926 in Liverpool. In 1926 he was elected to the chair of Pure Mathematics in the newly established Egyptian University, Cairo, where he found it a congenial task to build up a new department, and where he proved a most successful teacher and organiser. In 1931 he returned to this country to hold lectureships at Edinburgh (1931–32) and at Imperial College, South Kensington (1932–35); finally, in 1935 he returned once more to Edinburgh as head of the Department of Technical Mathematics, an office which he continued to hold for the few remaining years of his life.

Ince's mathematical research, represented by twenty-seven published papers, was devoted largely to the subject of Mathieu functions, the name given to the solutions of a differential equation originally solved by Mathieu in 1868 in connection with the vibrations of an electric membrane. He contributed three papers to *Monthly Notices* on the general solution of a differential equation (which may be regarded as an extended case of Mathieu's equation), which had been obtained by G. W. Hill in 1877 in his work on the mean motion of the lunar perigee. Ince held that an important part of

* Abstracted from the *Journal of the London Mathematical Society*, 16, 1941, by kind permission of the Editors.

a pure mathematician's duty is to provide tables for the use of physicists and astronomers, and he was well aware that the possibility of constructing such tables without a colossal expenditure of time and energy depends on the progress of theoretical analysis. He realised that in the existing state of the Mathieu theory the amount of labour required for the construction of tables was prohibitive, and he set himself to devise new analytical expedients. This he successfully accomplished, and after eight years of devotion to the task he published in 1932 tables of the characteristic numbers of Mathieu's equation and of the Mathieu functions, with their zeros and turning-points. It was a splendid piece of work, performed single-handed save for some help by an Egyptian assistant, and it will be more and more appreciated as the progress of physics and astronomy reveals fresh problems for which these tables provide the solution.

The mastery of the theory of linear differential equations which he acquired in his work on Mathieu and related functions is very evident in his large book *Ordinary Differential Equations*, which appeared in 1927. In two papers published in the last year of his life he made important contributions to the theory of Lamé's equation. Shortly before his death on 1941 March 16, the Royal Society of Edinburgh awarded him the Makdougall-Brisbane Prize, but he did not live to receive the honour.

In 1924 he married Phyllis, daughter of the late John Fry of Benhall, Suffolk, who survives him with two daughters.

He was elected a Fellow of the Society on 1916 December 8.

E. T. WHITTAKER

CHARLES WILLIAM JEFFRIES, Director of the Royal Observatory, Hong Kong, China, died suddenly from a stroke on 1941 June 22.

Born on 1882 April 28, he was the eldest son of the late James Jeffries of Greenwich, and was educated at the Royal Hospital School, Greenwich, winning the "Challenge" silver medal in 1896 awarded to the best scholar for two successive terms.

He joined the Royal Observatory, Greenwich, as a computer on 1897 April 20. It was in the meteorological department of the Observatory that he received his preliminary training in meteorology—the science in which he was subsequently destined to play a responsible rôle. His contemporaries at Greenwich will remember him best as a keen swimmer and hockey player.

Jeffries transferred to the Royal Observatory, Cape of Good Hope, on 1902 July 31, and was appointed to the permanent staff on 1903 December 22. Here, *inter alia*, he took an active part in the observing programme and compilation of the Cape Astrographic Catalogue.

On the recommendation of Sir David Gill, he was appointed First Assistant at the Royal Observatory, Hong Kong, on 1907 August 21, becoming Director on 1932 July 9 on the retirement of Mr. T. F. Claxton. He carried out his duties of weather forecasting for the disturbed area of the China Sea, made routine magnetic observations and maintained a continuous time service until the day of his death.

Jeffries was a man of great public spirit. His activities, both professional and social, covered a wide field. He was President of the Far East Regional *Commission de l'Organisation Meteorologique Internationale* in 1938, Chairman of the Association of Professional European Civil Servants and of the Civil Servants Council.

He remained a keen sportsman until the last and was an active member of several Hong Kong sports clubs.

Apart from his work he was an enthusiastic Freemason, having been Worshipful Master of three Lodges and District Grand Master of the Grand Lodge of Mark Master Masons of Hong Kong and South China since 1930.

He is survived by his widow and his only child Mrs. W. A. MacKinlay.

He was elected a Fellow of the Society on 1926 April 9.

FRANK JEFFRIES

JOHN MITCHELL was born in 1867 at Bank End, near Huddersfield. He was educated at Huddersfield Technical School and Christ's College, Cambridge, where he graduated with a first class in the Natural Science Tripos. Soon afterwards he entered the Wesleyan Ministry and in 1899 he went out to India, where, after spending several years on Missionary and Educational work, he founded and became Principal of the Bankara College in Bengal. The College and Hostel Buildings were opened in 1910 and 1912 respectively. Shortly afterwards the Observatory followed, and an electric lighting plant was installed in 1913. His energy and practical ability are summed up in the words of the College magazine—"He came to a town without any higher educational establishment: he left a fine group of buildings and a well-equipped College of the first grade."

It was in this observatory that some of the happiest hours of his life were spent. He took a keen interest in the Astronomical Society of India from its earliest days, and under its auspices lectured in Calcutta on several occasions. He was for ten years a member of the Senate of the Calcutta University.

In 1917 he returned to England to take up a business appointment in London. Although retired from the Wesleyan Ministry, he remained an ardent worker in Methodist circles. He was also soon prominent in the public life of Twickenham, where he lived, and became Mayor of Twickenham in 1927. In contrast to his life in India, he devoted what leisure he had to travel in northern countries, particularly in Iceland, which he visited no less than six times. Only in 1939 he accomplished the difficult climb of nearly 5000 feet to the summit of the Snæfellsjökull in western Iceland.

His later years were spent at Bourn in Cambridgeshire, where he was able to renew his associations with his old University. Even in retirement he could not remain inactive. He gave frequent lectures and was a regular local preacher.

He died very suddenly at his home in Bourn, owing to a heart attack, early in the morning of April 14, at the age of seventy-four.

He was elected a Fellow of the Society on 1891 January 9.

J. H. C. MITCHELL

DANIEL WALTER MOREHOUSE was born at Mankato, Minn., U.S.A., on 1876 February 22. After a childhood and early education in South Dakota, he entered Drake University, Des Moines, Iowa, in 1897. It was to this university that he devoted the greater part of his life and, after graduating in 1900, rendered notable services in the capacities of instructor, professor, dean, until ultimately in 1923 he reached the office of President, which he filled until his death on 1941 January 21.

His astronomical interests were centred on observations of comets and planets and on orbits of asteroids. For a period he worked in the University of Chicago, and it was at the Yerkes Observatory that he discovered, with the Bruce photographic refractor, the famous comet of 1908 which immortalizes his name. This comet, photographs of which adorn many a textbook, was remarkable for its nightly, or hourly, changes in structure and for its habit of throwing off parabolic caps, a phenomenon still surrounded with a certain degree of mystery. The discovery of this comet earned Morehouse the Donohoe Comet Medal.

From 1911–12 Morehouse pursued his researches and acted as instructor in the University of California, where in 1914 he received the degree of Ph.D. for work on the orbit of Jupiter VII.

At Drake University he performed immense services in the spheres of teaching and administration. The building of the Drake University Municipal Observatory was due to his initiative, and thanks to his continued zeal much was achieved there in observations and in public lectures. He could hold his audience well, and his visits to the Adler Planetarium as lecturer were eagerly anticipated.

Although primarily interested in the planetary regions of the solar system, his

enthusiasm took him to four total solar eclipses. Three of these were in U.S.A. (Colorado, 1918; California, 1922; Vermont, 1925). The fourth was that of 1927 in this country, which he observed at Giggleswick.

He married and had one son and two daughters. All three children married before his death, and two grandchildren cheered the closing days of his life.

His character has been warmly epitomized as follows: "Deep humility and unfailing courtesy, . . . a profound genuineness and sincerity, . . . a great love for his family and friends, spiritual aspirations to match his great stature, with human sympathy as broad as his great shoulders, a valiant crusader for understanding and tolerance." *

He was elected a Fellow of the Society on 1922 June 9.

RUDOLPH MORITZ was born in 1878, at Lenzie, Dumbartonshire, fourth son of Hermann Moritz, of Highgate, and died on 1940 August 20. After graduating B.Sc. of London University, he took up the legal profession. He entered Lincoln's Inn in 1899 and was called to the Bar in 1902. He made a speciality of patent law cases, and eventually took silk and was invited to the Bench on 1931 June 22.

His special interest in astronomy was in G. W. Hill's Lunar Theory and in E. W. Brown's continuation of it. At the beginning of this century the *Nautical Almanac* Office was at Gray's Inn, and his hobby took him there as a very frequent visitor. Subsequently he studied Relativity more thoroughly than is possible to most people. He published three papers in *Monthly Notices* on the motion of the lunar perigee.

He married Beatrice Helen Turnbull in 1906 and leaves one son.

He was elected a Fellow of the Society on 1931 November 13.

JAMES NANGLE, who had been Government Astronomer for New South Wales for fifteen years, died on 1941 February 22, while in his seventy-third year. He exerted an important influence in this State in the fields of architecture, education and astronomy. He began practice as an architect late last century, several large buildings in Sydney being designed by him, and he specialized in school and church buildings. He was President of the Royal Australian Institute of Architects in the year 1936–37, and was elected a Fellow of the Royal Institute of British Architects in 1937. Several papers on the properties of Australian timbers and building stones were published by him in the Journal of the Royal Society of New South Wales, which he joined in 1893, and of which he was President in the year 1920–21.

While still in practice he undertook some teaching in architecture at Sydney Technical College. In 1913 he was appointed Superintendent of Technical Education. He re-organized the basis of the technical education courses, bringing the Technical Colleges into closer touch with industries and trades by setting up a series of advisory committees, on which the professions and trades as well as educational authorities were represented. Similar internal committees provided for co-ordination of effort by the administrative and teaching staffs. He always stressed that a good system of technical education must be co-ordinated with the industries it was to serve. During his administration the attendance at Technical Colleges in New South Wales rose from four thousand to fourteen thousand. While he was Superintendent of Technical Education in New South Wales he paid extended visits to Western Australia and Tasmania to advise the governments of those States on the organization of their technical education systems. He retired in 1934.

One important task undertaken by James Nangle was the supervision of the

* Abstracted, in the absence of further information at the time of going to press, from the Obituary Notice by Philip Fox in *Popular Astronomy*, 49, 289, 1941, by kind permission of the Editors.

Vocational Training System for Returned Soldiers carried out by the Commonwealth Repatriation Department after the 1914–18 war. His services for this purpose were given by the Government of New South Wales to the Commonwealth Government, and altogether more than 20,000 returned soldiers who had been injured or whose training had been interrupted by active service were trained. He had to a marked degree the gift of the good administrator for obtaining co-operation and in making estimates of the absorptive capacities of the various trades and industries and carrying out the training of the men; he was very successful in getting the support of the trade unions, technical colleges and universities. He was awarded the O.B.E. in 1920.

His interest in astronomy began early. He joined the New South Wales Branch of the British Astronomical Association in 1905, and was its President on many occasions, his ability as a speaker being an asset to the meetings. He maintained an observatory at his residence in Marrickville until he became Government Astronomer in 1926, when the observatory had a difficult period through which his administration steered it. James Nangle was at all times most approachable and helpful to new-comers to the science of astronomy, and many have had their interest awakened by his numerous popular lectures and writings.

His friendliness and enthusiasm will be remembered by all who knew him. He is survived by his widow, daughter and three sons.

He was elected a Fellow of the Society on 1908 November 13.

CHARLES PENDLEBURY, who died on 1941 August 18, spent a life devoted mainly to the teaching of mathematics. His name will be remembered by a large number of pupils who benefited by his work as Senior Mathematical Master at St. Paul's School from 1877 to 1910, and by a still larger number of schoolboys in many lands who received their early mathematical training from his famous "Arithmetic".

Born on 1854 July 5, he received his education at Liverpool College and at St. John's College, Cambridge, where he was a Scholar, and in 1881 he graduated as 16th Wrangler in the Mathematical Tripos. From Cambridge he proceeded direct to the post at St. Paul's, where he revolutionized the methods of teaching mathematics; the majority of his pupils during his long service at St. Paul's were destined for Army careers. But he had many interests besides mathematics. He founded the School Rowing Club in 1880. Chess and walking tours, as instances of his recreations, indicate a well-balanced blend of physical and mental activity.

His mathematical career was marked by service to the Mathematical Association of even longer duration than that to St. Paul's School. This Association, founded in 1876 as the Association for the Improvement of Geometrical Teaching, became known by its present name in 1897. Pendlebury served for fifty years as Secretary from 1886 to 1936.

His versatility is also apparent from the fact that while still at St. Paul's, but especially after his retirement, he spent much time and energy on work for local Borough Councils.

His wife, Emily Coleborn, of Liverpool, whom he married in 1882, died in 1933.

He was elected a Fellow of the Society on 1879 January 10.

JOHN STANLEY PLASKETT, C.B.E., Gold Medallist of the Royal Astronomical Society, died at his home at Esquimalt, near Victoria, British Columbia, on 1941 October 17. In the fields of astrophysical research, of observatory organisation and direction, and in instrumental design and construction, Plaskett's contributions are so remarkable that it is sometimes difficult to realise that his first astronomical work was not undertaken until he was almost forty years of age. Yet a recently published bibliography of Plaskett's papers lists nearly ninety papers, and the equipment of many modern observatories

includes modifications to which he contributed. It is not merely coincidence that the great extension in research activity and public interest in astronomy in Canada has occurred during the years of Plaskett's astronomical work.

John Stanley Plaskett was the eldest son of Joseph and Annie Plaskett. He was born on a farm in Oxford County, near the town of Woodstock, in Southern Ontario, on 1865 November 17—two years before the Confederation of the Dominion of Canada. He completed the course in the local village elementary school and for some time attended the Woodstock High School. He was then needed on the home farm and worked there for some time. His interest had, however, always been in things mechanical, as shown by construction of apparatus at his home, and at his first opportunity he started to learn the machinist's trade in the town of Woodstock. Later his work as a mechanic took him to positions with the Edison Electric Company in Schenectady, New York, and with the Canadian Edison in Sherbrooke, Quebec. Thus by the time Plaskett was twenty-four he was a machinist with practical experience in the field of electrical equipment.

It was at this time that he was offered a position as mechanician in the Department of Physics of the University of Toronto. This position required that he construct apparatus for research and lecture experiments and that he assist in lecture demonstrations. Plaskett's interest and delight in all things mechanical made him a particularly able assistant, while the unfolding of the various fields of physics before him led him to the resolve that he himself would complete the undergraduate course in mathematics and physics.

His courage in undertaking to complete his Matriculation and then to start a long undergraduate course at the age of thirty is remarkable. The staff of the University allowed him to arrange his work so that he was able to carry on his mechanician duties as well as his studies, but the added burden meant long hours of hard study. He frequently used to tell us of this critical period of his life, and of the time when it was only the constant encouragement of his wife, Rebecca Hope Hemley, whom he had married in 1892, that kept him to the schedule he had set himself.

After graduating in 1899 in the honour course in mathematics and physics, he stayed on at the University until 1903. He was still a physicist and mechanic, and did considerable research in colour photography at this time. His first published work (1901), a paper read before the Royal Canadian Institute, dates from this time. It dealt with orthochromatic photography, being "Color Values in Monochrome."

Plaskett's formal astronomical career started with his appointment in 1903 to the staff of the new Dominion Observatory, which was being constructed at Ottawa. The reports of the Chief Astronomer for the few succeeding years contain the record of Plaskett's remarkable achievements. He did an excellent job preparing the apparatus for the Labrador Eclipse Expedition in 1905 and was soon placed in charge of the observatory's astrophysical work. While he carried on important spectroscopic researches on separate subjects such as Mira Ceti, novæ, solar rotation and binaries, the quest that runs through his whole Ottawa work was for better radial velocities with the 15-inch refractor, and he desired to increase its speed in order to reach fainter stars.

He found that the spectrograph as originally designed suffered from mechanical and optical defects. Mechanically the instrument was not sufficiently rigid to prevent flexure as the hour-angle changed during exposure. This led him to investigate the mechanical requirements for an ideal spectrograph. Similarly he carried on researches on the optical properties of the prisms and lenses to give the optimum results. He added to his own fine mechanical background much knowledge acquired on a trip to many of the American observatories, where he discussed the problems with leading astrophysicists. He then designed a new spectrograph for the 15-inch. He also added a correcting lens to this visual telescope to increase the speed in the photographic end of the spectrum. It has been stated that these improvements resulted in increasing the speed of this telescope to the equivalent of the great Yerkes refractor, for radial velocity

work. An ambitious programme of radial velocities was undertaken at Ottawa under Plaskett's direction.

In 1910 Plaskett attended the Mount Wilson meeting of the International Union for Co-operation in Solar Research. With his background it was natural that he should be fascinated by the size and perfection of the 60-inch reflector. It must have been rather discouraging for Canadian officials, very proud of their fine new Dominion Observatory, to be confronted in 1911 by Plaskett's recommendation that the Government undertake to construct a new telescope of at least 72-inch aperture!

The Chief Astronomer, Dr. W. F. King, stood behind Plaskett in his campaign, but much of the burden of actually convincing the department heads and members of Parliament that the new observatory was necessary fell to Plaskett. It is a tribute to his success with the 15-inch, his confidence in his ability to perform the greater task, and his cheerful but persistent personality that, by 1913, the negotiations were complete and the contract let.

The design and construction of the 72-inch telescope gave Plaskett great scope for his mechanical ingenuity, and he was responsible for many of the excellent features incorporated in this fine telescope. His association at that time with Brashear and with Warner and Swasey led, after his retirement, to his serving as a consultant to Warner and Swasey, notably in the case of the McDonald 82-inch telescope. This work helped him to maintain his active scientific interests in the later years of his life.

From the opening of the Dominion Astrophysical Observatory, in Victoria, B.C., in 1918 under Dr. Plaskett's direction, until his retirement in 1935, he carried on many research programmes, often in collaboration with other members of his staff. Naturally his interest was at first in the accumulation of observations of radial velocity. For this work the telescope had been largely designed and was very efficient. Many new binaries were discovered and orbits determined by various members of the staff. These included "Plaskett's Star" in 1922.

As spectra accumulated, Plaskett became particularly interested in the early-type O and B stars. These he considered as individual stars of interest in their own right, as stars in which stationary calcium lines were readily obtained, and later as stars of high luminosity, and hence at great distances in space.

While most of Plaskett's work was published in the publications of the Dominion and Dominion Astrophysical Observatories, during the past twenty years he contributed to the *Monthly Notices* eight papers, as well as his annual reports as Director. These papers give a good survey of his activity during the Victoria phase of his career.

His many papers published elsewhere, dealing with spectroscopic binaries, have a single representative in *M.N.*, **82**, 447, 1922, in which he deals with the most spectacular of his contributions to binaries—the early-type star B.D. $+6°1309$—for a long time by far the most massive star known. His work on the high-temperature stars is illustrated in a paper on "Three Peculiar Spectra" (*M.N.*, **87**, 31, 1926) and the George Darwin Lecture (*M.N.*, **90**, 616, 1930), in which he surveyed the whole problem of the nature and motions of these stars. His work on interstellar calcium is represented by papers in 1923 and 1930 (with J. A. Pearce) dealing with the H and K lines in the O-type Stars and with the Motions and Distribution of Interstellar Matter.

Plaskett's long years of securing stellar spectra and measuring radial velocities bore perhaps their most spectacular fruit in the contribution they made to the problem of galactic rotation. His early-type, distant stars gave particularly important information on this problem. Papers were contributed on the "Rotation of the Galaxy" (*M.N.*, **88**, 395, 1928), the "Distance and Direction of the Gravitational Centre of the Galaxy from Motions of the O5 to B7 Stars" (with Pearce) (*M.N.*, **94**, 679, 1934), and "An Analysis of the *K*-term in B-type Stars" (*M.N.*, **98**, 518, 1938). The general problem is treated much more fully in a classical series of papers in Vol. V of the *Publications of the Dominion Astrophysical Observatory*.

Apart from Plaskett's great instrumental achievements, as illustrated in several of the large modern telescopes and spectrographs, and the great mass of major research papers he has published, Plaskett made two other notable contributions—his cultivation of the interest of the general public in astronomy, and the guidance he furnished to many other astronomers, especially youthful Canadians with whom he came in contact.

In popularisation of astronomy he was proud of the tens of thousands of visitors who visited the observatory in Victoria each year. He also was a past president of the Royal Astronomical Society of Canada, and wrote many papers for its *Journal.*

Plaskett's work received many formal recognitions. As well as his greatly cherished Gold Medal of the Royal Astronomical Society, he received the Bruce Medal of the Astronomical Society of the Pacific, the Rumford Medal of the American Academy of Arts and Sciences, the Henry Draper Medal of the National Academy of Sciences, Washington, and the Flavelle Medal of the Royal Society of Canada.

The Universities of Toronto, British Columbia, Queen's and McGill, in his native land, and the University of Pittsburgh, in Pennsylvania, awarded him honorary doctorates.

Plaskett is survived by his widow, a son, Stuart, in Victoria, and his elder son, Harry Hemley Plaskett, Savilian Professor of Astronomy at Oxford University. The close association of this son and his father in their astronomical work, the help they received from one another, and the intense pride each showed in the other, was always a source of great pleasure to the friends of either or both.

FRANK S. HOGG

SALLIE DUFFIELD PROCTOR-SMYTH (*née* Thompson) was born on 1856 February 3 at St. Joseph, Missouri. Her first marriage was to R. J. Crawley, of Belfast, Ireland, with whom she went to Australia, where they lived until Mr. Crawley's death in 1880. Mrs. Crawley then returned to her home in Missouri with her two little daughters, and shortly afterwards met R. A. Proctor (then a widower with six children) and married him in 1881. Soon after their marriage they went to live in England, where they lived at Kew until 1884, when the whole family removed to the United States, settling eventually at Orange Lake, Florida. But the isolation and other drawbacks led them to decide to return to England, and in 1888 September Mr. Proctor left Florida to make a home for his family in his native land, intending to send for them as soon as possible; but on arrival in New York he was taken ill, and died next day, apparently from a chill on the top of malaria. On learning of her husband's death Mrs. Proctor hurried to New York, and with great courage and devotion determined to take his place for the lectures which he had engaged to give in England. She immediately sailed for England and fulfilled every one of these engagements, reading from the manuscripts which he had prepared. Through the influence of many well-known scientists she obtained a Civil List pension of £100. By Mr. Proctor she had two sons who died in childhood.

In 1890 Mrs. Proctor married Dr. J. C. Smyth, of Belfast, and they made their home at Altrincham in Cheshire. Mr. Smyth died in 1905, but his widow remained at Altrincham until after the marriage of her elder daughter (Rachel Crawley) to Mr. Macaffee, of Castlerock, Ireland. Later, Mrs. Proctor-Smyth joined her daughter at Castlerock (her younger daughter having died at Altrincham many years earlier) and lived there until her death, which occurred on 1941 March 10. Mrs. Proctor-Smyth was always keenly interested in astronomy, and took a deep interest in Mr. Proctor's magazine *Knowledge* from its inception until the day it ceased publication. In 1891 she was closely associated with a project (first suggested by S. W. Burnham of Lick Observatory) to raise a sum of five thousand pounds for the erection of a Proctor Memorial Observatory at San Miguel, California. Unfortunately the plan did not materialize, but the details were used later in the planning of the Chabot Observatory, Oakland, Cal., by other Lick astronomers.

Mrs. Proctor-Smyth was elected a Fellow of the Society on 1916 May 12, and was thus one of the earliest women members to be elected after the granting in 1915 of the Supplemental Charter enabling women to become Fellows.

MARY PROCTOR

MARY, LADY SALTOUN was the only daughter of Thomas Arthur Grattan-Bellew, M.P. In 1885 she married the 18th Baron Saltoun (creation 1445), who was a Representative Peer of Scotland from 1890 to 1933; there were four children, three sons and one daughter. She was a lady of great charm and was keenly interested in the modern developments of astronomy.

She was elected a Fellow of the Society on 1937 January 8.

HENRY JOHN WILKINS was born on 1865 November 17 in Berkshire. At the age of eleven he won a choral foundation scholarship at New College School, Oxford, and after continuing his education at St. Catherine's graduated with honours in Lit.Hum. in 1887. He spent a year as classical master at Graigmore College and, despite a desire to go to the Bar, was ordained deacon in 1889. He became curate and later vicar at St. Jude's, Bristol, where he distinguished himself by his versatile and benevolent activities. Later he became vicar of Westbury-on-Trym, Bristol, where he remained for forty-one years until his death on 1941 June 23. In addition to astronomy, architecture and ecclesiastical history were numbered among his private interests; he carried out research into the history of his own church and this formed the subject of one of his published books; another dealt with excavations at Glastonbury Abbey. He received the degree of Doctor of Divinity from Oxford University in 1906.

He married late in life and is survived by his widow.

He was elected a Fellow of the Society on 1922 April 12.

ANNIE JUMP CANNON, who died on 1941 April 13, was born in Dover, Delaware, U.S.A., on 1863 December 11. Her mother was an intelligent and sympathetic woman of Quaker training, *née* Mary Elizabeth Jump; her father, a shipbuilder named Wilson Lee Cannon. After attending schools in Dover she entered Wellesley College at the age of sixteen, graduating four years later in the class of 1884 with the Bachelor's degree. The next ten years were spent largely at her home in Dover, although in 1892 she travelled to Spain to observe an eclipse of the Sun. The death of her mother, to whom she was very closely bound, was a severe blow. It was at that time, 1893 December, that she turned to astronomy as a "solace and life work." During the next two years she took graduate studies at Wellesley and at Radcliffe College in Cambridge, Massachusetts. In 1896, E. C. Pickering appointed her assistant in the Harvard College Observatory, asking her to undertake the task of classifying stellar spectra. This was the beginning of her lifelong association with the observatory. In 1911 she became Curator of Astronomical Photographs; in 1938, William Cranch Bond Astronomer. She officially retired from the staff in the summer of 1940 but actually kept up her work until a few weeks before her death. The classification of spectra is being continued by her experienced and capable assistant, Mrs. Margaret Walton Mayall.

Miss Cannon was one of several extremely able women selected for astronomical research by Pickering during his administration of the observatory. Others were Mrs. Wilhelmina P. Fleming, Miss Antonia C. Maury and Miss Henrietta S. Leavitt.

In those pioneer days of modern astronomical spectroscopy Pickering was guide and counsellor. Indicative of his greatness as a man and a scientist is the fact that Miss Cannon, who knew him so intimately, came to regard him with deep respect and

admiration. In addition to breadth of vision, Pickering had a remarkable devotion to long systematic programmes. When Miss Cannon referred to detailed work that seemed to offer little immediate return, he encouraged her by saying with enthusiasm that it was "cumulative."

The spectroscopic work of the Harvard Observatory constitutes a great memorial to Henry Draper, who in 1872 obtained the first photograph of a stellar spectrum (that of Vega) in which individual lines were clearly visible. After Dr. Draper's death in 1882, the investigation was given generous financial support by Mrs. Draper. A tremendous development began in 1885, when Pickering, reverting to the objective prism used by Fraunhofer and Secchi, undertook an extensive photographic survey of stellar spectra.

Study of the photographs revealed the existence of a single continuous spectral sequence which would include all except a very small fraction of the stars. Moreover, it became obvious that numerous classes—certainly more than the four given by Secchi —would be required to provide adequate descriptions of individual spectra. Accordingly, for the classification of about 10,000 stars in the original *Draper Catalogue*, Mrs. Fleming arranged a sequence of spectral types to which were assigned the letters A to N.

In Miss Cannon's development of this scheme for her more detailed study of 1122 bright southern stars, it was found convenient to retain only the letters B, A, F, G, K, M, and to indicate intermediate spectra by numbers representing tenths of the intervals. Concerning the interchange of letters A and B, Miss Cannon wrote (*Harv. Annals*, 28, 140, 1897): "The evidence that the Orion spectra [Class B] precede the Sirian [Class A] is as good as that the Sirian precede the solar. The gradual decrease in the intensities of the Orion lines is accompanied by gradual increase in the hydrogen lines, and by the incoming of faint solar lines, so that in spectra of Classes B8A and B9A, solar and Orion lines are commingled. Hence it was necessary either to interchange the letters B and A of the *Draper Catalogue* or to place the letter B before the letter A. The first alternative would prove confusing. The second presents no real difficulties since the letters are merely symbols to express an observed condition." The adoption of this system of classification by a committee of the Solar Union secured its universal acceptance. The system with some extensions and modifications was stabilized in 1922 by the approval of the International Astronomical Union at its first meeting in Rome. A few minor improvements have been introduced at later meetings. It is now customary to submit all proposed changes to the Union for official sanction.

Miss Maury, in a study of bright northern stars which paralleled that of Miss Cannon on southern stars, formulated a system employing the roman numerals from I to XXII. This nomenclature never had wide adoption, but the auxiliary symbol *c* for certain types of spectra with narrow lines, in current use, serves to remind us of Miss Maury's splendid pioneering.

Upon the completion of the intensive studies of stellar spectra by Miss Cannon and Miss Maury, Pickering began a project to revise the original *Draper Catalogue* and to extend it to include the magnitudes and spectral classifications of fainter stars—about a quarter of a million of them. Of this undertaking Professor Solon I. Bailey says (*History and Work of the Harvard Observatory*, p. 157): "It was the culmination of the life efforts of Edward C. Pickering, and the center of his interests during the closing years of his life." The results are embodied in the *Henry Draper Catalogue* comprising nine large volumes of the *Harvard Annals* (91 to 99). Miss Cannon, operating with marvellous speed and accuracy, completed practically all her portion of the work for this immense catalogue during the four years beginning in 1911 October. Assistants selected and identified the stars and recorded the data, but she herself did all the classifying. Her superb skill in interpreting photographs of spectra became manifest, not only in the reliable classifications, but in her unerring detection and grouping of peculiar stars such as those with bright lines or composite spectra. The *Henry Draper*

Catalogue, the "Cambridge Durchmusterung", is a great reference work to which the whole astronomical world turns for data on stellar spectra and magnitudes. But it is more; it is a storehouse of pertinent and revealing remarks on numerous individual spectra—a storehouse whose treasures will stimulate and assist specialized investigations for a generation to come. Additional work for the *Henry Draper Extension*, on stars for the Eros campaign, and for those in the zones of the Yale and Cape of Good Hope catalogues, brought the total number of spectra classified by Miss Cannon to about 350,000.

This monumental achievement, undoubtedly Miss Cannon's greatest contribution to science, was by no means her only one. She discovered five novæ and about 300 variable stars. Her telescopic work at Cambridge, chiefly on variable stars, was kept up for years. In 1922 she devoted six months to photographic observing at the Arequipa, Peru, station of the Harvard Observatory. She published descriptions of the spectra of novæ and of many other peculiar stars. In 1907 she compiled a catalogue of 1380 variables, and in 1926 co-operated with S. D. Townley and Leon Campbell in publishing a list, containing many detailed data, of 1760 long-period variables. She maintained an ever-expanding card index to the literature of variable stars, of great value to her colleagues at Harvard and, indirectly, to many other astronomers.

Her scientific achievements brought many honours. She was one of the very few women Honorary Members of the Royal Astronomical Society. All are shown in the following table:—

Honorary Members

	Elected	Died
Miss Herschel	1835	1848
Mrs. Somerville	1835	1872
Miss Sheepshanks	1862	1876
Miss Clerke	1903	1907
Lady Huggins	1903	1915
Mrs. Fleming	1906	1911
Miss Cannon	1914	1941

Following the death of Lady Huggins, Miss Cannon was for twenty-five years the sole Honorary Member of the Society. In addition to the Bachelor's degree in 1884, Wellesley College gave her a Master's degree in 1907, an LL.D. in 1925. Other institutions to confer the doctorate were Oxford, Groningen, Mount Holyoke, Oglethorpe, Delaware. She was the only woman ever to receive the Henry Draper medal of the National Academy of Sciences. When awarded the Ellen Richards Research Prize in 1932, she promptly turned the money over to the American Astronomical Society to establish the Annie Jump Cannon Prize for women astronomers. She was an active member of numerous academic and scientific societies.

Miss Cannon travelled frequently, probably because she loved people and cherished rich friendships in many places. She attended many scientific gatherings in the United States as well as nearly all the meetings of the International Astronomical Union. Toward the end of her life she developed the habit of spending her summer vacations in England. Possessed of an engaging personality, she made hosts of friends, and through her vivid memory kept them all within quick and sympathetic mental call. Her priceless ability of being good company for all kinds of people, old and young, astronomers and laymen, was never withheld; and the more she used it, the greater it became. What she once wrote of a colleague, "The human touch has never been lost amidst all his scientific activities," is notably true of Miss Cannon herself. Her character, distinguished by modesty and unselfishness, was human nature at its best.

PAUL W. MERRILL

ROBERT EMDEN * was born on 1862 March 4 in St. Gallen, Switzerland. He studied mathematics and physics at Heidelberg, Berlin and Strassburg, and took his doctorate at Strassburg with a thesis on the vapour pressure of salt solutions. In 1899 he obtained an appointment at the Technische Hochschule at Munich, and also (at the desire of Prof. Seeliger) was made honorary professor of astrophysics in the university. He remained at Munich until 1934, when he retired to Zürich. His scientific activity continued until the end, and his last paper, on the temperature problems of lakes, was in the press at the time of his death, which occurred on 1940 October 8.

Almost all Emden's work relates to the applications of thermodynamics to natural phenomena. His published papers are about equally divided between geophysics and astrophysics. For many years he was a keen balloonist, and in 1910 he published a book on the principles of balloon navigation. With Prof. Finsterwald he made the first important advances in photogrammetric measurement from the air. It is remarkable that his famous book *Gaskugeln* (1907) was practically his first contribution to astrophysics. But he had already formed another kind of connection with astronomy, having married Klara Schwarzschild, sister of Karl Schwarzschild. The years 1906–7 are memorable in astrophysics for the perfecting of the theory of convective equilibrium by Emden and the beginning of the theory of radiative equilibrium by Schwarzschild. *Gaskugeln* includes a short section (pp. 320–332) on Schwarzschild's theory of radiative equilibrium of the Sun's atmosphere, which had just appeared; but the rest of the book is a study of convective equilibrium, applied especially to the interior of a star, but also to nebulæ and other cosmic distributions of particles and to the earth's atmosphere.

It appears from the preface that the origin of *Gaskugeln* was a course of instruction at the Technische Hochschule planned to counteract the prevailing tendency to make the study of physics too abstract. The stars were brought in to provide natural applications of physical laws instead of the usual artificial examples. It was also well suited to train the students in numerical computation—a subject too much neglected in the colleges—for "the beginner finds it easier to derive formal relations than to evaluate them in absolute measure." This practical attitude to physical principles is evident in all Emden's work; a casual illustration is afforded by his letter to *Nature* in 1938 entitled "Why do we have winter heating?"

Between Homer Lane's pioneer paper in 1869 and Emden's book in 1907, the one fertile investigator of convective equilibrium in the stars was A. Ritter. Other writers appear to have contributed nothing original except mistakes. Emden gives high tribute and generous acknowledgements to Ritter; and the credit for the advance may perhaps be divided equally between the two men. But it was Emden's more systematic survey, and his practical attention to the needs of actual computation, which has given the work its outstanding value—a value scarcely lessened by the change-over from convective to radiative theory. Emden's "polytropes" form a series of self-consistent stellar models with progressively increasing central condensation. In the study of a star or spherical nebula one may, as a first rough approximation, treat the internal density as uniform. A polytrope provides a second approximation which may be fitted to any desired degree of central condensation; and Emden's theoretical methods and computed tables are the basis of all investigations of this kind. His work will always rank as a great classic; though the progress to which it has led now often demands a third approximation, and calculations by direct quadratures which do not depend on the Emden models are increasingly common.

In 1930 Emden took a leading part in founding the *Zeitschrift f. Astrophysik*. Though almost seventy, he took up the plan with great zeal, and the success of the journal is in no small measure due to him.

He was elected an Associate of the Society on 1932 June 10.

A. S. EDDINGTON

* Notice held over from 1941.

FRIEDRICH WILHELM HANS LUDENDORFF was born at Thunow, near Köslin, in Pomerania, on 1873 May 26. He was a younger brother of General Ludendorff, famous in the war of 1914–18. He entered into astronomical work in 1897 as assistant at the Hamburg Observatory, where he was chiefly engaged in observations of minor planets and comets. In the following year he became assistant at the Potsdam Astrophysical Observatory, then under the directorship of H. C. Vogel. In Potsdam Ludendorff remained for the rest of his life; in 1905 he was appointed observer, and in 1921 he succeeded G. Müller as director of the observatory. He had only recently retired from the directorship when he died on 1941 June 26.

When Ludendorff first came to Potsdam, one of his duties was measuring plates for the Astrographic Catalogue. In connection with this work he published a characteristically thorough study of the various errors exhibited by photographic copies of réseaus, with particular attention to distortion of the photographic emulsion.

Through Vogel's influence Ludendorff's interest was soon attracted to work on stellar radial velocities. Ludendorff became a very active observer who secured, in collaboration with his friend Eberhard, in fifteen years several thousand spectrograms of stars with variable radial velocities and in particular of spectroscopic binaries. These furnished material for numerous papers on radial velocity curves and orbits which were mostly published between 1905 and 1915 in the *Astronomische Nachrichten*. Among the stars which Ludendorff investigated was ϵ Aurigæ. His spectroscopic observations of this star, covering more than twelve years, combined with an exhaustive study of its light variation, established that it is an eclipsing binary with the unprecedented period of twenty-seven years, and that the radial velocity curve follows in general the variations in light.

Besides studying individual spectroscopic binaries, Ludendorff soon started statistical investigations of computed orbits. One notable result which he found in 1910, independently of Campbell and Schlesinger, was the increase of the eccentricity of orbits with increasing length of period. Investigations on the masses of spectroscopic binaries of different spectral type, which he began in 1910, contributed to establishing the great increase in mass for stars of O- and early B-type, compared with stars of later types, a result which we now regard as a particular instance of the general mass-luminosity relation. His work on stars with variable radial velocities included cepheids, and he was among the first to draw attention to the existence of changes in the radial velocity curves of certain cepheids which have since been shown to be accompanied by similar changes in the light-curve.

Perhaps Ludendorff's best known work is his statistical study of the light-curves of variable stars, chiefly of cepheids and long-period variables. He discovered that Me variables show an increase of the average range of light variation with increasing length of period, while variables without emission lines vary within a smaller range. In order to find how far the various forms of light-curves were related to the length of period and range of light variation, Ludendorff introduced his system of classification of light-curves and established a close correlation both for long-period variables and cepheids between a given type of light-curve and the period. In 1924 he proposed his system of classification of variable stars in which ten types, including novæ and eclipsing binaries, were distinguished according to their light-curves. Ludendorff's admirable survey of the whole subject of variable stars from the observer's point of view forms one of the best contributions to the *Handbuch der Astrophysik*.

In the field of solar physics Ludendorff investigated the relation which exists between variations of solar activity at different sunspot maxima and the time of their occurrence after the preceding minima. He also published two well-known papers on changes of the form of the solar corona and their correlation with solar activity.

One of Ludendorff's most valuable contributions to astrophysics was his investigation of the spectrum of the solar corona. He made the necessary observations during the

eclipse of 1923, which he observed in Mexico, and published his results in 1925. In a very careful spectrophotometric comparison he found the intensity distribution in the coronal spectrum to coincide with that in the normal solar spectrum within $0^{m}.1$ at most. When Grotrian, at the eclipse of 1929, confirmed and extended this result over a wider range of wave-lengths, he had very little to add to Ludendorff's excellent technique.

During the last ten years of his life, Ludendorff's interest was largely absorbed by his investigations on the astronomy of the Maya civilization in ancient Central America. He had always been greatly attracted by the history of astronomy and had published several papers relating to Renaissance astronomy. His interest in the Maya was largely aroused during his visits to Central and South America. In a series of about a dozen publications (beginning in 1930), Ludendorff established the astronomical significance of the majority of Maya inscriptions. Many of these consist largely of sets of dates which were found to represent the times of conspicuous celestial phenomena like eclipses, oppositions of planets, and conjunctions of planets with the Sun, with each other and with bright stars in the ecliptic. At least in some cases Ludendorff could show reasons why a particular set of dates and phenomena was recorded in a particular inscription, and could demonstrate how improbable it would be to assume that the observed coincidences between Maya dates and astronomical phenomena were due to chance. The Maya were thus shown to have been people with a surprising knowledge of astronomy, acquainted with the prediction of eclipses and both the synodic and sidereal periods of the planets, who when they introduced their calendar about 600 B.C. must have already had at their disposal records of astronomical phenomena which dated considerably further back.

Ludendorff's contribution to the *Handbuch der Astrophysik* has already been mentioned. He also spent much time as joint editor in order to bring the extensive programme of the *Handbuch* to a satisfactory conclusion. Much earlier he had, as contributor and later on as editor, helped to publish the last four editions of Newcomb-Engelmann's *Populäre Astronomie*, which twenty years ago was one of the standard textbooks on descriptive astronomy in Germany.

Work at Potsdam Observatory while Ludendorff directed it covered a wide range of problems of astrophysics and stellar astronomy, including much purely physical spectroscopy. One of the major programmes in which Ludendorff took a special interest was the Spektral-Durchmusterung of the southern Kapteyn fields, for which the material had been secured at the temporary station at La Paz, Bolivia, which had been planned and set up through the initiative of Ludendorff and Kohlschütter.

Ludendorff was a member of the Preussische Akademie der Wissenschaften. He joined the Astronomische Gesellschaft in 1898 and served as its secretary from 1920 to 1930. In 1933 he became its president and was twice re-elected. He was a regular attendant and a popular figure at A.G. meetings, and he came as guest to the Leiden and Stockholm meetings of the I.A.U.

His private life was devoted to his family. Colleagues were welcomed in his circle with cordial hospitality. It was not always possible to agree with Ludendorff's views, but his generous and straightforward character made him greatly respected everywhere.

He was elected an Associate of the Society on 1932 June 10.

H. A. BRÜCK

PROCEEDINGS OF OBSERVATORIES

At the request of Council, Directors of Observatories have submitted notes on their proceedings during the two years 1940 and 1941. The following represent either reports by the Directors themselves or abstracts made by the Editors from notes supplied by the Directors. The list of contributing observatories is shorter than usual, but includes all those from which notes have been received at the time of going to press; in view of current difficulties in postal communication, the omission of any particular observatory must not necessarily be interpreted as a sign that there has been a total interruption of work.

Royal Observatory, Greenwich
(*Director, Dr. H. Spencer Jones, F.R.S., Astronomer Royal*)

During the two years under review much of the normal work of the Royal Observatory has been suspended. At the beginning of the war, the objectives of the 26-inch and 28-inch refractors were dismounted as a safety measure and observations with these instruments were suspended. The intensive air raids on the London area, which commenced in 1940 September, made night observing impossible. Because of the danger to the instrumental equipment, the objectives of the reversible transit circle and its two collimators, the micrometer eye-end, the 36-inch mirror and auxiliary mirrors of the Yapp reflector, the optical parts of the spectrograph and the objective of the Cookson Floating Telescope were dismounted; these parts, together with the 26-inch and 28-inch objectives, were sent away from Greenwich for safety.

Certain members of the staff, with special qualifications, have been loaned for work of national importance; others have been released for work in various branches of the Admiralty, whilst a number have joined H.M. Forces.

The buildings have received damage on several occasions by enemy action. The north wing of the main building and the south portico of the altazimuth building have both received direct hits from bombs. The main gates and supporting pillars have been destroyed by a direct hit. The damage to the observatory, though considerable, is not serious. The original Wren building of 1675 is substantially undamaged, except for damage to windows, window-frames and ceilings. The coverings of the altazimuth and transit pavilion domes have been destroyed, and those of the 26-inch and 28-inch refractors have been riddled with holes. The instrumental damage has been, fortunately, of a minor nature. A Cooke small transit instrument, which had been mounted in the altazimuth dome, was thrown from its mounting and broken in half, but the object-glass was undamaged. A personal equation machine had been constructed and fitted to the south collimator for the investigation of personal equations; but neither this machine nor the objective of the collimator were damaged when the portico was hit.

The annual results of observations with the Airy Transit Circle of the Sun, Moon and planets for the years 1937 to 1940 are in course of preparation. The preparation of a star catalogue, based on the observations from 1931 to 1938, which had been delayed by the extensive investigations with the reversible transit circle, is in progress.

The observations with the reversible transit circle for providing the foundations of a system of right ascensions were continued until 1940 September. They are found to have a very high precision. The instrument was extremely sensitive to temperature effects, caused by changes of air temperature and of direction of wind. The experiment of jacketing the piers with felt was tried, and the rapid fluctuations of level error were materially reduced. It is hoped that when observations with this instrument are resumed a more complete jacketing will practically eliminate these changes of level.

The observations for determining the errors of the divisions of the fixed circle were completed and have been analysed. The principal errors are recurrent every $2\frac{1}{2}°$. The extreme range in the division errors is about $0''{\cdot}75$.

The plates obtained with the Cookson Zenith Telescope, up to the time when observations were suspended, are being measured for the derivation of the latitude variation.

The completed series of parallax plates, taken with the Thompson Equatorial, have been measured and the parallaxes of 28 stars have been published. A large number of proper-motion plates, which had remained unmeasured owing to heavy parallax measuring and the completion of the colour-temperature discussion, are now being measured.

The discussion of the observations of Eros obtained at the opposition of 1931 has been completed, and values of the solar parallax and of the mass of the Moon have been derived. The results have recently been published by the Society.

Photographs of the Sun with the photoheliograph and observations with the spectrohelioscope have been obtained when conditions permitted. It was considered inadvisable to risk the transport of the photographs obtained at the Cape after the outbreak of war. The measurement of the Greenwich photographs has proceeded, but complete results for the year 1939 and subsequent years will necessarily have to be deferred until after the end of the war. The decline of activity from the high maximum of 1937–38 has continued, but there has been no general scarcity of spots, and several of very large spots, associated with considerable disturbance, have appeared. In the vicinity of several of these spots, bright eruptions causing a radio fade-out have occurred, which have been followed by a magnetic storm; it has been possible to determine precisely the interval between the solar disturbance and the sudden commencement of the magnetic storm. The intervals have ranged from 17 to 22 hours.

The time service was removed from Greenwich in 1940 September. Two time stations, each completely equipped with telescope, clocks, chronographs and radio receivers, are in regular operation and working in close co-ordination with each other. Both stations send out time signals regularly as a matter of routine; arrangements have been made by which the time signals are actually radiated from that station at which conditions are the most stable. This close co-ordination between two separate stations has been found advantageous; not infrequently the sky is clear at one station when it is cloudy at the other, and a more complete control over the going of the clocks at both stations is provided by the combination of the observations at the two stations.

Nautical Almanac Office.—The work of the Office has been continued without sensible modification or undue interruption in spite of the difficulties, both temporary and permanent, arising from the war.

Difficulties of printing, and the destruction by enemy action of the copy, the type and the plates for upwards of 3000 pages of various Office publications, have delayed appreciably the acceleration in publication planned for the *Nautical*, *Abridged Nautical* and *Air Almanacs*. The publication of both the *Abridged Nautical Almanac* and the *Air Almanac* has, however, recently been speeded up to meet the increasing difficulties of distribution, and considerable improvement will be shown for both the *Nautical Almanac* and the volume of *Apparent Places of Fundamental Stars* for 1943. The following publications have been issued since 1940 January 1:—

Publication	*Published (or to be published)*
Nautical Almanac, 1941	February, 1940.
Nautical Almanac, 1942	November, 1941.
Nautical Almanac, 1943	(March, 1942).
Abridged Nautical Almanac, 1941.	March, 1940.
Abridged Nautical Almanac, 1942	May, 1941.
Abridged Nautical Almanac, 1943	(March, 1942).
Apparent Places of Fundamental Stars, 1941	May, 1940.
Apparent Places of Fundamental Stars, 1942	October, 1941.
Apparent Places of Fundamental Stars, 1943	(June, 1942).
Air Almanac, 2nd Quarter, 1940, to 2nd Quarter, 1942 ...	About 3 months in advance.

In addition, the copy for the ten outstanding volumes of the *Astronomical Navigation Tables* was completed by 1940 November, and they were issued shortly afterwards.

While the ephemeral data of the *Nautical Almanac* has remained generally unchanged, various changes have been made with the principal object of reducing its size. The edition for 1941 was reduced by the omission of the apparent places of all but 208 stars, in accordance with the resolutions of the International Astronomical Union. In 1942, the explanation and tables were drastically revised by the omission of all permanent data not directly relevant to the use of the *Almanac*; lists of Observatories and Standard Times were also omitted as being of little value at the present time. These omissions were made as a part of a general policy of separating the purely ephemeral matter from the permanent and semi-permanent tables and explanations; it is intended, as soon as circumstances permit, to publish a comprehensive supplement containing all the omitted portions together with such other tables and information as the wider scope of a supplement will allow. With the exception of the omission of the Occultation Reduction Elements, no further changes are envisaged.

The programme of occultation prediction has of necessity been continually revised owing to the difficulty of transmitting predictions to enemy or enemy-occupied countries. As predictions are normally made two or three years in advance, it is difficult to foretell for what observatories predictions will be required; at present, predictions are being made for all stations with which communication is possible, and duplicated times are being taken from the occultation machine for all other stations. These will be immediately available for transmission to the observatories concerned when that becomes possible. The Occultation Reduction Elements for 1942 were omitted from the *Almanac* for that year but complete copy was sent to America for publication there. Dr. D. Brouwer and Dr. W. J. Eckert were instrumental in arranging for this to be published under the auspices of the American Section of the International Astronomical Union.

An analysis of observed and reduced occultations since 1937, the year in which the reduction elements were first introduced, has shown that the anticipated increase in the number of observations has not materialised, and that the amount of work in computing reduction elements for all occulted stars brighter than magnitude 7·5 is considerably greater than that necessary to reduce all the observations individually. Accordingly, it has been decided to suspend the computation of the reduction elements, and they will not be published for 1943 onwards; the Nautical Almanac Office has, however, undertaken to reduce all observed occultations normally catered for by the reduction elements. Full details of the scheme, which it is hoped will lead to centralised publication of the reduced occultations, will shortly be published.

The only change introduced into the *Abridged Nautical Almanac* is the inclusion from 1942 onwards of sunrise, twilight, moonrise, etc. tables for latitudes from 61° N. to 73° N. No change has been made to the *Air Almanac*, though from 1943 onwards it will be published in 4-monthly parts instead of quarterly.

The volume of *Apparent Places of Fundamental Stars* depends entirely on computations received under international exchange agreements; the computation of those

portions that could not be obtained from the exchanging countries has, for 1942 onwards, been shared between the Office of the *American Ephemeris* and the *Nautical Almanac* Office. The editions for 1943 and 1944 have thus been ensured, and it is anticipated that similar arrangements can be made, if necessary, for subsequent years. In 1943, the French, German and Spanish introductions will be omitted, but otherwise there will be no change of content.

Royal Observatory, Edinburgh

(*Director, Professor W. M. H. Greaves, Astronomer Royal for Scotland*)

The war has naturally slowed down the research activities of the observatory. Apart from the observing difficulties arising from black-out restrictions, the transfer of one member of the staff to duties elsewhere was reflected in a reduced research output. But the routine activities of the observatory, including the supply of a local time service to the city of Edinburgh and the maintenance of seismological and meteorological observations, have been continued without interruption, as has also the measurement of the times of reception of the Rugby 10^h signals against the free pendulum clock Shortt No. 4. These measures are forwarded to the Royal Observatory, Greenwich, and are utilised for the inclusion of Shortt No. 4 in the Greenwich "Mean Clock."

In spite of the difficulties it is possible to report that some research progress has been made, and that the measurement of line intensities in early-type stellar spectra and the search for variable stars in the Kapteyn selected areas have been continued.

With regard to the line-intensity work, plates taken with the 36-inch reflector and spectrograph have been measured with the microphotometer, but little progress has been made with the reduction of the measures as far as the main programme is concerned. Some special investigations, however, have been carried out by Dr. I. H. Abdel-Rahman who, as a research student in the University of Edinburgh, worked at the observatory from 1939 October to the summer of 1941. Dr. Rahman's researches included a set of measurements of the intensities of the *Si* III triplet λλ 4552, 4567 and 4574, and these measures, together with a discussion of the results, have been published in *M.N.*, **101**, 7. Dr. Rahman has confirmed the result previously found that the intensities of these lines in stellar spectra are proportional to the square roots of the theoretical emission intensities, calculated according to the summation rules. This indicates that the lines fall on the damping section of the curve of growth, and Dr. Rahman has called attention to a discrepancy which appears when the observational material is examined in the light of existing theory. In addition to this work, Dr. Rahman has measured the intensities of lines in several Be-type spectra, concentrating especially on the variable Be stars.

The examination of the Kapteyn selected areas 2–19 for variable stars has been continued on the lines indicated in previous reports. The plates, which cover an area of 36 square degrees, are taken with the 10-inch Grubb-Parsons triplet lens, and examined with the blink-comparator described in the *Publications of the Royal Observatory, Edinburgh*, Part I, No. 1, which also describes the method used in adjusting the triplet. During the period covered by this report the lens was cleaned and readjusted.

As this work progresses, it becomes more and more apparent that for purposes of classification, as opposed to mere discovery and position measurement, a large amount of observational material is essential. In area 8, a galactic area in Cassiopeia, difficulties of classification have proved much greater than in the earlier areas blinked. In part this is due to the faintness of the stars concerned, some being well seen only at maxima or on a few plates taken under the best observing conditions. Accordingly, attention has been paid to augmenting the material, not only for areas 8, 9 and 10, but also for areas 2, 4, 6 and 7, in which unclassified variables have already been discovered. The methods

of searching for periods are apparently satisfactory, as they have disclosed the periods of all known periodic variables in the areas. The blinking of the plates is also satisfactory in that it showed most of the known objects or those of them which might be expected to appear. Thus, in area 8, of the 18 known variables, 14 were found in blinking; one could not be seen at the published position, which is probably erroneous; two eclipsing stars (one with a range of only 0·3 mag.) were not picked up (though two other eclipsing stars were found); so that only one star which might have been expected to show up did not do so. The blinking, on the other hand, gave some seventy other stars which will certainly give a high proportion of new variables, as well as a larger number with too small a range to be worth examining further. All stars of known large proper motion were found.

Royal Observatory, Cape of Good Hope
(*Director, Dr. J. Jackson, F.R.S., H.M. Astronomer*)

During 1940 the observing staff was gradually reduced to about half the normal number. An attempt, however, has been made to carry on the more essential parts of the programme and especially to make those observations which cannot be replaced by others made at a later date. Consideration has been given to the loss of observations in Europe as a result of the war situation.

As usual the major portion of the staff has been engaged in work with the reversible transit circle and with the parallax programme of the Victoria Telescope. With the former some 14,000 observations in all have been secured in the two years. General work refers to the observation of the Boss and Backlund-Hough stars commenced in 1936. The work is well advanced. After the outbreak of war observations of the Moon were started and in the two years 112 observations were secured, mostly between first quarter and full moon. The Sun, major planets and the four large minor planets have been observed regularly, including observations of Mercury on no less than 183 days.

In the parallax programme 5800 plates were taken and 4500 measured. Since 1926 the parallaxes of 1180 stars have been determined and the proper motion in declination as well as in Right Ascension of 600 of them. During recent years the number of plates used for parallax determination has been increasing steadily from 20 to 30, and the interval covered by the observations is now generally three years or more. The proper motion in R.A. is thus more accurately determined. The total number of known stars with annual proper motion greater than 0″·2 and bright enough to be easily observed with the telescope does not exceed 2000. In certain R.A.'s, especially 3″–6″, the stars in our programme are being exhausted and gaps have been filled by repeating some of the more important stars, or stars for which anomalous results were obtained.

The reduction of staff has greatly reduced the rate of progress in determining the positions of stars with the wide-angle lens. After the measurement of the plates in the zones $-30°$ to $-35°$ and $-35°$ to $-40°$ was completed, the zone $-40°$ to $-52°$, which is well covered by our Astrographic Zones, was passed and work was started on the zone $-52°$ to $-56°$. About two-thirds of the plates of this zone have been measured. No start has been made in getting meridian observations of reference stars or of getting plates of the next zone, on account of the small amount of help available.

The copy for press of the zone $-30°$ to $-35°$ is completed as far as the position and proper motions are concerned. It is intended to give accurate photographic and photovisual magnitudes of all stars as well as spectral types. The work of standardizing the magnitudes of the 9 Harvard Standard E regions centred at declination $-45°$ and of comparing the zone plates with these regions is nearly completed. About 90 per cent. of the stars are in the Henry Draper Catalogue, so that spectral types are available. It is hoped to get spectral types for most of the other stars from plates to be taken at the

Bloemfontein branch of the Harvard Observatory, and Professor Cillié has expressed his desire to carry out the classification.

The principal departures of our work from the long established routine have been in connection with the Total Eclipse of the Sun on 1940 October 1, and with the observation of bright comets at the beginning of 1941. An account of the expedition to observe the former, with plates showing the corona, was printed in *Occasional Notes*, No. 9 (1941 June) and the observations of the comets have been published (*M.N.*, **101**, 334).

The occultations of stars predicted in the *Nautical Almanac* have been observed when possible. It is pleasant to record that Mr. H. E. Krumm of Capetown has also observed a number of occultations in 1941. Mr. W. P. Hirst has observed a selected list of double stars with the 7-inch refractor. Mr. R. de Kock, who discovered Comet 1941 *c* at Paarl, has now moved to Capetown where he is continuing his observations of variable stars with the 7-inch Heliometer at the Observatory.

Cambridge Observatory
(*Director, Sir A. S. Eddington, O.M., F.R.S.*)

A programme of photoelectric observations of the variable star 12 Lacertæ, in co-operation with Prof. E. Fath at the Lick Observatory, was carried out in the autumn of 1940; and the Cambridge results have been published in *M.N.*, **101**, 43. Measures were obtained by Mr. Green on twenty nights from August 30 to October 29, including eight nights on which the star was observed throughout a complete light-period. The conditions were favourable for high accuracy, and the small variations of amplitude were clearly shown.

A new photoelectric photometer, designed by Dr. Brück for use with the Sheepshanks telescope, has been set up. The construction of this instrument was based on the experience gained with a photometer of similar design which is being successfully used in investigations of the solar spectrum at the Solar Physics Observatory. The photoelectric currents are amplified by means of a D.C. amplifier in which an electrometer triode and grid-leak resistances of 100,000 megohms are employed. To make the performance independent of small fluctuations of the supply voltage, a bridge circuit containing two electrometer triodes with matched characteristics has been introduced. For the sake of greater electrical stability the valves, grid-leak resistances and photoelectric cell are operated in a vacuum. The instrument has been arranged so that either steady deflections or rate-of-drift measurements can be used. Difficulties in securing the necessary matched valves have caused considerable delay, but the instrument is expected soon to be ready for use.

Dr. Brück and Mr. Green have carried out an investigation of radial velocities of δ Cephei from four-prism spectrograms obtained at the Solar Physics Observatory. Results have been published in *M.N.*, **101**, 376.

Papers by the Director on "The Cause of Cepheid Pulsation" and on "Ionisation Equilibrium in a Convective Region" have been published in *M.N.*, **101**, 177, 182. There seems to be strong theoretical ground for concluding that liability to pulsation is determined by the extent of the critical hydrogen layer which lies not far below the photosphere. According to the usual calculations the layer has too small a mass to produce the required effect; but an examination of the effect of convection in the critical layer suggests that the apparent discrepancy can be overcome, and at the same time indicates a cause for the excessive amount of high-frequency radiation in stellar atmospheres.

Courses of practical instruction were given by Dr. Brück. The Saturday evening exhibitions of celestial objects with the Northumberland and Thorrowgood telescopes in the winter terms were partially resumed, but were restricted to moonlight nights.

Solar Physics Observatory, Cambridge University
(*Deputy Director, Mr. W. Moss*)

Solar Work.—Work with the spectroheliograph has been continued during the years 1940 and 1941, and spectroheliograms of the solar disc and limb in K and *Hα* light have been secured. Observations have also been made with the spectrohelioscope with which some small chromospheric eruptions were recorded. In the summer of 1941 spectrohelioscope observations were directed mainly towards comparisons of helium D_3 and hydrogen *Hα* radiation in prominences. Differences in structure have been noted which are to be investigated further by means of simultaneous photographs of D_3 and *Hα* in prominences with the Rowland concave grating.

The study of the solar spectrum with the photoelectric photometer attached to the McClean spectroscope had to be interrupted in 1940. It was continued in the summer of 1941 when a considerable number of records of Fraunhofer lines in the blue and violet regions of the spectrum was obtained. The programme is to be continued further and extended towards longer wave-lengths. The investigation of individual prominent lines in the region so far studied is nearly complete. Some additional tracings have been secured which provide preliminary material for a complete photometry of parts of the solar spectrum based on photoelectric observations.

The theoretical darkening towards the Sun's limb in convective equilibrium has been investigated under the assumption that the absorption coefficient is roughly proportional to the total pressure. This work and statistical investigations of the number and distribution of sunspots and faculæ on the solar disc have been published in the *Monthly Notices.*

Stellar Work.—Apart from observations of lunar occultations, stellar work has been entirely confined to studies of spectrograms which had been obtained earlier. The spectrophotometric programme on line intensities in K-type stars has been continued. Measurements of a number of lines due to *H*, *Na*, *Mg*, *Fe*, *Cr*, *Ti*, and Ba^+ in 80 stars have been completed. Improved spectral types have been derived with a probable error of about $\pm 0{\cdot}05$. Two notable discoveries have been the exceptional sensitivity to changes in luminosity of three satellite lines in an iron multiplet, and the sensitivity to temperature of three chromium lines. After allowance for errors, the dispersion in intensity of lines in stars of given type and luminosity may be ascribed to a standard deviation in abundance of the elements amounting to between 10 and 20 per cent.

Spectrophotometric investigations have also been made of the emission and absorption bands of Nova Herculis and Nova Lacertæ, of β Lyr, γ Cas subsequent to its brightening in 1936, and of α CVn. In the case of Nova Lacertæ contours of $H\beta$ have so far been studied on 60 spectrograms taken between 1936 June 20 and September 16, but the material has not yet been further discussed. The investigation of β Lyr has also not yet been concluded.

A study of the radial velocity curve of δ Cep has been published which was made to test the existence of relative displacements between lines of different origin.

A statistical analysis has also been made of errors in estimates of spectral types and of differences between trigonometric and spectroscopic parallaxes.

University Observatory, Glasgow
(*Director, Professor W. M. Smart*)

The researches undertaken during the two years under review have been mainly on problems of stellar kinematics.

The preliminary work on the Analysis of the Proper Motions of the General Catalogue has made further progress, almost reaching the point where the analysis according to

regions begins. It is not anticipated, however, that much time can be devoted to this extensive research in the immediate future.

The Director and Dr. Tannahill have assisted in the navigational instruction of R.A.F. Cadets who have come to the University for a general training in scientific subjects.

The following Research Students have continued their work in the observatory: Akbar Ali, M.A., B.Sc., Ph.D., A. Brown, M.A., and P. C. Chaudhuri, M.Sc., Ph.D.

The following papers have been published :—

W. M. Smart, "The K Term and the Galactic Rotational Constants," *M.N.*, **100**, 370; "The Systematic Corrections to the Proper Motions of the General Catalogue," *M.N.*, **101**, 37.

W. M. Smart and A. Ali, "The Perseus Cluster," *M.N.*, **100**, 560.

W. M. Smart and T. R. Tannahill, "Star-streaming in Relation to Spectral Type from the Cape Photographic Proper Motions," *M.N.*, **100**, 688.

T. R. Tannahill, "The Clear-Day Barometric Curve at Ben Nevis," *P.R.S.E.*, **61**, 71.

A. Ali, "The Corona Borealis Cluster," *M.N.*, **100**, 570; "A Critical Examination of the Leander McCormick Proper Motions," *M.N.*, **101**, 317; "Solar Motion and Galactic Rotation from O- and B-type stars," *M.N.*, **101**, 324.

P. C. Chaudhuri, "The 61 Cygni Cluster," *M.N.*, **100**, 574.

The Director was appointed Halley Lecturer at Oxford for 1941 and took as his subject "Sea and Air Navigation"; the lecture has been published by the Oxford University Press.

Imperial College Observatory, South Kensington
(*Director, Professor H. Dingle, D.Sc.*)

At the beginning of the war all instruction in Astronomy stopped. It has, however, been resumed in 1941 so far as it does not involve observations during hours of darkness. Laboratory spectroscopic work has been greatly reduced, but Mr. Akhtar has continued his solar studies in a restricted way, and hopes to obtain some definite results shortly. So far as possible astronomical work will be continued throughout the war, though necessarily on a smaller scale than formerly. It is gratifying that a large number of students have enrolled for the courses, despite the difficulties of work in London.

University of London Observatory, Mill Hill
(*Director, Mr. C. C. L. Gregory, M.A., Wilson Observer*)

As previously reported, a few days before war was declared the Observatory was closed down, and the instruments dismantled and stored underground. In the early summer of 1940, however, the 24-in. Wilson Reflector was made available for use and a series of spectrograms of γ Cas obtained. On 1940 July 11 it was observed that certain of the Balmer lines in the spectrum of this star had become composite, and later some rapid and rather striking changes were also noted in helium lines. No significant changes have been observed since 1940 November 22. A total of thirty spectra were obtained during 1940 autumn, despite frequent accompaniment of falling bombs and gun-fire; on one occasion the telescope was bodily moved $\frac{3}{4}$-inch, but fortunately the actual damage did not exceed two holes in the roof.

University Observatory, Oxford
(Acting Director, Dr. M. G. Adam)

During the period under review there has been a progressive withdrawal of the astronomical staff of the Observatory for war-work.

Apart from the astrographic telescope and visual refractor, the equipment of the observatory has been partially dismantled and the optical parts stored for safety in the seismological basement. The mechanical parts of the solar telescope and spectroscope have as far as possible been protected by sand-bags; regular inspection and frequent greasing have prevented any deterioration of these parts in their enforced idleness.

Consequent upon the withdrawal of the staff for other duties little new astronomical work has been initiated during the war, and such investigations as have been completed had their origin in earlier years. An investigation on the numerical integration of the equation of transfer for absorption lines (*M.N.*, **101**, 3) by the director lead to an observational determination of the variation of η (the ratio of line to continuous absorption coefficients) with depth in the solar atmosphere. Dr. Adam completed her study of the behaviour of faint lines towards the limb of the Sun (*M.N.*, **100**, 595), and was able to show that the unexpected strengthening at the limb, first discovered by her in 1937, probably arises from an isothermal layer in the solar atmosphere. Dr. Evans's interesting study of the variation of $H\alpha$ across the solar disc (*M.N.*, **100**, 156) showed that, contrary to a suggestion by Unsöld, uncompensated cycles play a relatively unimportant part in the formation of this line. This work led him in turn also to consider the question of the numerical integration of the equation of transfer, and a theoretical note on this "inverse" problem has been communicated by him to the Society (*M.N.*, **101**, 21).

Norman Lockyer Observatory, Sidmouth
(Director, Mr. D. L. Edwards)

Work has been continued without interruption, though on a rather reduced scale owing to the shortage of staff and other war-time difficulties. Night work in particular has had to be somewhat curtailed, but it has only been rarely that a good observing night has passed without being utilized.

The work has included the determination of relative gradients and colour temperatures from objective-prism spectra, and the commencement of a detailed survey of galactic clusters. Several papers on the latter subject have already been published. Results have also been published on a photometric "fog effect," arising when two or more exposures are made on one plate, and on the variable star XZ Aur, which has been shown to be an N-type variable.

The present programme of work covers a continuation of the above subjects, as well as a study of γ Cas, including its changes in spectrum, magnitudes (photographic and photovisual), colour indices and colour temperatures. A number of measures of magnitudes has already been completed, in addition to much work on the spectrum.

David Dunlap Observatory, University of Toronto
(Director, Professor R. K. Young)

Spectrographic Work.—This report covers the work of the observatory from 1940 January to 1942 January. During this interval 1799 spectrograms have been taken with the 12-inch camera and one-prism spectrograph on the two programmes mentioned in the last report. The first of these comprises all stars down to photographic magnitude 7·5 in an area 6×6 degrees centred around the Kapteyn areas of the northern hemisphere. The areas within 4×4 square degrees are already finished. The second comprises all stars brighter than visual magnitude 6·00 in Schlesinger's Bright Star Catalogue for which

no radial velocities are published. The first of these programmes is practically finished. There remain a few plates to be obtained in the region 5–10 hours and these should be observed early in 1942. The measuring of the plates has fallen somewhat behind owing to the depletion of the staff for war work. In 1940 July, Mr. G. H. Tidy joined the Canadian Navy, Dr. J. F. Heard entered the Air Force in 1940 November, and in 1941 January Dr. P. M. Millman became an instructor in the Air Navigation School, Rivers, Man. Miss Northcott has investigated the spectroscopic binary HD 93075 and derives a preliminary period of 1·8052 days. Mr. A. F. Bunker, under the direction of Dr. F. S. Hogg, carried out an investigation of seven peculiar strontium-line stars. In general the peculiar stars have been found to be cooler than comparison stars of the same general spectral type. The results of this work appear as *D.D.O. Pub.*, **1**, No. 10. Before leaving, Dr. Heard completed some investigations on the spectrum and velocity variations of HD 142926. These results appear as *D.D.O. Pub.*, **1**, No. 9.

Newtonian Focus.—131 Newtonian plates of globular clusters were obtained in 1940 and 80 in 1941. Periods of 5 variables in the Hercules cluster have been obtained, including a correction to Barnard's Variable No. 1. An abstract of this work appears in *Pub. A.A.S.*, **10**. Periods of three interesting variables, with periods greater than one day, in Messier 56 have been reported to the A.A.S. The brightest variable in the region appears to have a period of 51 days and a range of two magnitudes. A number of new variables in southern globular clusters have been found on plates obtained at the Stewart Observatory by searching with a newly built blink microscope. Most of the new variables are in the clusters Messier 22 and Messier 80. This work was carried out by Dr. Helen Sawyer Hogg.

Meteor Observation.—Prior to joining the Air Force, Dr. Millman carried out observations of the chief meteor showers occurring in 1940, using the new multiple camera mounting with rotating shutter. Two spectra and 13 direct meteor photographs were secured at the Dunlap Observatory, and 60 direct photographs were secured at co-operating stations. The air path of a bright meteorite which fell near Dresden, Ontario, was computed from about 100 visual observations. The results of these investigations appear as *D.D.O. Comm.*, No. 7, and in Meteor News of the *Journal R.A.S.C.*, **33**, 34.

Instrumental.—The chief piece of apparatus constructed for the observatory during the interval has been a 7-foot vacuum tank for aluminizing the large mirror. This has been brought to a successful conclusion and the mirror aluminized. The aluminium coat divides the exposure time in two, which we had been accustomed to give to record the K line in one-prism spectra. An account of this apparatus will appear as *D.D.O. Comm.*, No. 8.

Dominion Astrophysical Observatory, Victoria, B.C.
(*Director, Dr. J. A. Pearce*)

Staff.—During the period under review the observatory has suffered grievous loss in the deaths of its two senior astronomers. Dr. W. E. Harper, Director, 1935–40, died on 1940 June 4, and Dr. J. S. Plaskett, Founder and Director, 1917–35, died on 1941 October 17.

Dr. A. McKellar was granted leave of absence to lecture in physics at the University of British Columbia during the academic year 1941–42.

Instruments.—Preparations have been made for aluminizing the 72-inch mirror. Plans are also in progress for increasing the resolving power of the existing stellar spectrograph, by converting it into Littrow-form and effectively into a 6-prism instrument. This device will permit the alternative use of two Wood aluminium-on-glass gratings.

An instrument with which profiles of absorption lines may be derived by mechanical graphical methods in one-tenth the usual time has been constructed.

Programme.—A large number of investigations in progress or completed include the following:—

(1) Studies of Class B stars fainter than the 7th magnitude, north of the celestial equator. This programme occupies about 40 per cent. of the observing time of the telescope.

(2) The radial velocities of 150 A- and B-type stars, previously studied but requiring revision.

(3) Investigations of dynamical and physical properties of spectroscopic and eclipsing binaries; studies of the following stars have either been published or are essentially complete—θ^2 Tau, κ Cnc, H.D. 23277, 34762, 203858, 207650, 207826, 227696.

H.D. 199140 has been shown to be a variable of β Cephei type and not a spectroscopic binary.

The apsidal motions of AR Cas and TX UMa have been studied with especial thoroughness; apsidal periods of 435 ± 125 and $35{\cdot}6 \pm 0{\cdot}42$ years respectively have been found.

(4) Investigations of Wolf-Rayet, P Cygni and Emission-line stars include a study of the peculiar spectrum variable H.D. 190073. The hydrogen line profiles of this star may be interpreted in terms of a normal A type reversing layer with an overlying expanding envelope producing a profile of P Cygni type. Similar conclusions are suggested by the *Ca*II profiles. Radii of layers of the expanding shell varying from $3{\cdot}4r_*$ for the emission component of *Ca*II to $1000r_*$ for the self-reversal component are found.

(5) Studies of R- and N-type stars brighter than the 9th magnitude; in the course of this programme, the lithium resonance line, λ 6708, has been found as a strong absorption in the star WZ Cassiopeiæ. This is the first evidence of extra-terrestrial lithium apart from the solar spectrum.

(6) The photo-electric determination of colours of distant stars.

(7) An investigation of line intensities in G-type stars, especially γ Cygni, α Persei, α Canis Minoris compared with the solar spectrum.

(8) Molecular Spectra: from a study of the spectra of diatomic molecules the interstellar lines $\lambda\lambda$ 4300·3, 3874·6, 3934·3 have been identified with the molecules *CH*, *CN*, *NaH* respectively. The identifications with *CH*, *CN* have been confirmed by the successful prediction of other lines later observed by Adams. The observations point to a "rotational" temperature of about $2^\circ K$. A table has been prepared giving wavelengths of lines arising from the lowest states of about 30 common diatomic molecules composed of at least one cosmically abundant atom.

The spectrum of Comet Cunningham (1940 *c*) was photographed with unusual purity. The *CN* band at 3883 A. showed some very interesting structural details.

Helwan Observatory
(*Director, Dr. M. R. Madwar*)

Time Service.—The time service was maintained as usual, the error of the Standard Sidereal clock Shortt No. 1 being determined from star transits. Rhythmic W/T signals were received daily from Bordeaux and Rugby.

The numbers of transits taken throughout the years 1940, 1941 were 29 and 41 respectively.

Reynolds Reflector.—The telescope was used on 25 nights in 1940. 21 plates were exposed on various nebulæ. As a precaution against damage by air raids the telescope was dismounted on 1940 June 12.

Occultations.—Lunar occultation observations were started at the observatory in 1941, and 23 observations were made.

General.—The usual magnetic, seismological and meteorological observations were continued as before.

Union Observatory, Johannesburg
(*Union Astronomer, Dr. W. H. van den Bos*)

26½-Inch Visual Refractor.—1166 micrometrical measures of double stars were made during 1940, and 1195 during 1941. Some cinematographic observations of the Moon, Mars, Jupiter and Saturn were obtained.

Occultations of Stars by the Moon.—127 and 108 observations of occultations of stars by the Moon were obtained during the years 1940, 1941 respectively.

Franklin-Adams Star Camera.—During the two years plates were taken with this instrument, distributed as follows:—

	1940	1941
Variable Star Regions	573	250 plates
Minor Planet Regions	276	220 ,,
Comets	1	51 ,,
Miscellaneous	14	
Total ...	864	521 plates

Staff.—Dr. H. E. Wood retired on pension on February 3. He had been on the staff since 1906, Union Astronomer since 1928 January 1.

The staff on 1941 December 31 was constituted as follows:—

Senior Astronomer:	W. S. Finsen, M.Sc.
Astronomer:	C. Jackson, B.Sc. (on Active Service).
Assistant Astronomers:	E. L. Johnson (on Active Service).
	J. A. Bruwer, B.Sc.
	. . . . . (vacancy).
Clerk:	Miss S. S. Bosman.

Dr. H. van Gent worked at the observatory during the whole of the period under review. Dr. W. Chr. Martin left in 1941 January for the Bosscha Observatory, Java.

Radcliffe Observatory, Pretoria
(*Director, Dr. H. Knox-Shaw, Radcliffe Observer*)

The observatory has suffered a grievous loss in the death of Mr. E. G. Williams, which took place after a few weeks' illness on 1940 May 31. During the first half of 1940 the observational work mentioned in the last report was continued by Dr. Redman and Mr. Williams. Preparations for the eclipse of 1940 October 1 were then begun. At Calvinia Dr. Redman, with the assistance of Dr. Zanstra, successfully photographed the transition from the Fraunhofer to the chromospheric spectrum, employing the moving-plate spectrograph which was to have been used by the Cambridge expedition. This instrument has since been re-erected at the observatory to test observationally a theory of Dr. Zanstra's with regard to the polarisation of light within the Fraunhofer lines coming from near the Sun's limb. Three papers by Drs. Zanstra and Redman on this problem have been published by the Society. Dr. Zanstra has also been engaged on some theoretical research on the Balmer continuous spectrum in planetary nebulæ, and on a problem suggested by Dr. Redman, viz. the scattering of light in the sky and in optical instruments. The 3-inch refractor has been used by the Director for the observation of occultations. The Director has also completed the reduction of the photometric observations of B stars made by Mr. Williams, which has led to a scrutiny of the adopted magnitudes of all the brighter southern stars. The compilation of a card catalogue of southern B stars is nearly finished.

During 1941 Dr. Redman has been engaged on the reduction of his plates taken at the 1940 eclipse.

The 74-inch mirror which, as a precaution, was buried at the outbreak of war was

disinterred early in 1940. Work on it has continued in Newcastle since 1940 March, as opportunity has offered, and it is now approaching its final state. Nothing has been done to the Cassegrain spectrograph since the war started.

Kodaikanal Observatory
(*Director, Dr. A. L. Narayan*)

A direct reading photoelectric spectrophotometer was constructed and preliminary results of observation with this instrument on a few Fraunhofer lines were published.

A statistical study of the variation of prominence areas was published which showed that there is a correspondence between the variation of the Earth-Sun distance and the variation of the mean prominence area.

Results of the measurement of cosmic ray intensity at Kodaikanal and Agra were published.

A series of papers on the motion of gases in the Sun's atmosphere was published. These showed that it is possible to explain, on purely dynamical considerations, many of the major peculiarities of solar dark markings and prominences, such as the variation of their inclination to the meridians with variation in latitude, their westward inclination to the solar radius, etc. These papers embodied also a purely dynamical theory capable of explaining the observed heights of the chromosphere and the reversing layer and the observed height of an average quiescent prominence.

Commonwealth Solar Observatory, Canberra, Australia
(*Director, Dr. R. v. d. R. Woolley*)

Total Solar Eclipse 1940 October 1.—An expedition from the Commonwealth Solar Observatory observed the total eclipse of the Sun 1940 October 1. Dr. C. W Allen went to Calvinia and was favoured with good weather. He made measurements of the polarisation of the corona through blue and red filters, and on another instrument obtained the Fraunhofer spectrum of the corona. Mr. A. J. Higgs went to Victoria West and studied the effects produced within the ionosphere during the eclipse. Reduction of the results is almost complete and two preliminary papers have been published in *Monthly Notices*.

It was found that the polarisation of the corona was almost independent of colour and of distance from the Sun's limb. The usual emission lines were found in the coronal spectrum near the Sun's limb, and faint absorption lines were observed in the fainter regions. These were not as intense as in the solar spectrum, and the intensity ratio corona/Sun increased with limb distance but was independent of wave-length. A red shift of the coronal lines relative to Fraunhofer lines of about 6 km./sec. has been detected but the probable error is of the same order. Further discussion of the results is awaiting better times.

Measurements of the atmospheric ozone were made during the eclipse with a Dobson photoelectric spectrophotometer.

Fraunhofer Lines.—A study has been made of the variation of equivalent breadths and central intensities of twenty Fraunhofer lines in the violet and blue regions of the Sun's spectrum. Although the work is not concluded the results obtained are: (*a*) there is no measurable difference between the central intensities or equivalent breadths of lines at the equatorial limb and the polar limb; (*b*) the increase in breadth of faint lines as one approaches the Sun's limb is consistent with an assumption that the Sun's atmosphere is in a state of non-isotropic turbulence with a greater horizontal than vertical velocity.

Observations of the transit of Mercury on 1940 November 11–12 were made with the Sun Tower Telescope. Nine satisfactory plates were obtained, the result of their measurement appearing in *M.N.*, **101**, 103, 1941.

The other astronomical activities of the observatory have been abandoned on account of the war.

Staff.—Mr. N. G. Chamberlain was appointed Research Fellow on 1940 February 26. Mr. D. W. N. Stibbs was appointed Assistant on 1940 August 14.

Riverview College Observatory, Riverview, N.S.W.
(*Director, Rev. D. O'Connell, S.J.*)

The programme of photographic work on variable stars has been continued in spite of difficulties, such as a greatly reduced staff, due to the war. *Riverview Publication* No. 5, containing papers on variable stars by J. Voûte and D. O'Connell, was distributed in 1940. Studies on a number of Cepheid variables and eclipsing binaries, including some with moving apsides, are in course of preparation.

Sydney Observatory
(*Acting Government Astronomer, Mr. H. W. Wood, M.Sc.*)

Mr. James Nangle, who had been Government Astronomer for New South Wales for sixteen years, died on 1941 February 22. Mr. E. E. Adderley resigned during November from his position as Assistant Astronomer at the observatory. This leaves the Acting Government Astronomer as the only professional member of the staff. For two months during the first half of 1941 Dr. J. G. Voûte visited the observatory and measured a number of double stars on astrographic plates.

During the period under review volumes 21, 22 and 24 of the Sydney Section of the *Astrographic Catalogue* have been printed and distributed. During the year measurements of plates and preparation of manuscript have been continued, and there are now five volumes ready to go to the printer, and ten more are in an advanced stage. Observations of reference stars continued until 1941 November.

The occultations predicted in the *Nautical Almanac* have been observed when possible, those for 1940 having been reduced and published in the *Monthly Notices* and the occultations observed during 1941 are now being reduced. The reductions have been carried out in duplicate on the occultation cards, one set being forwarded to Yale Observatory. The contact times of the Transit of Mercury on 1940 November 12 were observed and have been published in *Monthly Notices.*

Visual observations of the magnitude of Comet 1941 *c* were made and the results published in the *B.A.A. Journal.*

The civil work of the observatory has been continued as usual. This consists in the supply of astronomical memoranda, astronomical information for legal purposes and the time service. The educational work of the observatory has also been continued and lectures on astronomy have been delivered regularly. During the period under review nearly 2500 persons have visited the observatory to be shown the uses of the various instruments, and on fine nights they were given an opportunity to look through the telescope. Lectures and demonstrations were given to students of the University and Teachers' College.

Dominion Observatory, Wellington, New Zealand
(*Acting Director, Mr. R. C. Hayes*)

Time Service Department.—Commencing on 1940 January 1, the Onogo modified system was adopted for the main radio time-signals which originate at this observatory, and are transmitted daily by the Wellington Radio Station.

On 1940 November 12, observations of the Transit of Mercury were made with the transit instrument, as part of a programme of observations of the transit organized by the Carter Observatory.

A Precision Pendulum, previously installed in the observatory basement, has been developed into a Free Pendulum, and is operated in conjunction with a Synchronome Slave-Clock. Although the Free Pendulum is not under constant pressure, its rate is considerably steadier than that of any of the other clocks.

Publications.—Publications have consisted mainly of seismological reports and bulletins.

Mr. Robert Barker's Observatory, Cheshunt, Herts

1940.—The favourable apparition of Venus afforded meridional observations over many weeks. A south collar with Anchises Regio and Hero Regio were constantly observed.

Differences from charted records of the lunar parallel Mersenius clefts, E. of Gassendi, have been noted.

Observations were often made despite considerable risk during air raids.

1941.—Over fifty observations of Mars near opposition were secured, and a complete chart of the planet made with detail of antarctic maria.

A new lunar cleft from Pitatus, over 100 miles in length, has been observed, and many smaller features, hitherto unrecorded, have been discovered.

Telescope: 12·6 in. Calver Reflector, clock-driven equatorial, 120-in. F.L.

Mr. J. Evershed's Observatory, Ewhurst, Surrey

Routine work with the spectroheliograph has been much restricted during the past two years, but co-operation with Kodaikanal has been maintained.

The liquid prism spectrograph has been employed in obtaining high dispersion spectra of sunspots and solar rotation spectra in the red region, where the effect of atmospheric scattering of general sunlight is less than in the more refrangible region. Experiments have been and are being made to determine whether such scattering can account for low values of the rotation speed which some of the measurements indicate.

The success of the method of multiple transmission through a single liquid prism of great optical perfection has justified the employment of two more prisms of the same type, but larger aperture, recently designed and constructed by Mr. F. J. Hargreaves, one of these being a reflecting prism. With this equipment interesting details have been revealed in the magnetic fields in sunspots, details which have not hitherto been recorded.

Dr. J. L. Haughton's Observatory, Teddington *

The year opened very favourably as far as weather was concerned, 10 occultations being observed up till May 13. In June the 8-inch mirror was aluminised, but with increased aerial activity and longer hours of official work, observation became more and more difficult and finally, in September, the optical parts of the telescopes were removed to a place of greater safety.

Slight damage was sustained by the structure of the observatory on two occasions, owing to enemy action, but, as far as can be ascertained, none of the apparatus has suffered.

Mr. M. B. B. Heath's Observatory, Kingsteignton, Devon

Daylight observations of Mercury were made on 41 days during 1940 and 9 drawings were made. In 1941 similar observations were made on 14 days and 4 drawings were made.

Daylight observations of Venus were made on 108 days during 1940 and 51 drawings were made. In 1941 similar observations were made on 15 days and 1 drawing was made.

Mars was observed on 57 nights between May 4 and December 24 during 1941 and 14 drawings were made.

* Report for the year 1940.

Mr. F. M. Holborn's Observatory, Streatham

The usual programme of work for the British Astronomical Association was carried on until 1940 September, when the observatory was closed down owing to all spare leisure being needed for whole-time Civil Defence work. In those eight months upwards of 1000 observations were made of variable stars and novæ.

Mr. A. M. Newbegin's Observatory, Worthing, Sussex

For reasons connected with the war this observatory was closed down at the end of 1940 June, the instruments being dismantled and stored away in safety. At the time of writing it has not been practicable to restart observations, but it is hoped to resume work at an early date.

Mr. B. M. Peek's Observatory, Solihull, Birmingham

In spite of difficulties, it was possible for the main work of the observatory to be continued during the winter of 1940–41; interruptions during 1941–42 have fortunately been few and the usual programme has been carried through up to the time of writing.

Photometric observations of Nova Persei 1901 have been made somewhat intermittently, but the study of the surface features of Jupiter has been regularly pursued.

Fifteen occultations of stars by the Moon were recorded in 1941.

Arising from the discussion of a long series of observations obtained during the latter half of 1940, a paper entitled "A Remarkable Spot on Jupiter" was submitted to the Society and has appeared in *M.N.*, **101**, 70, 1941.

The work of collating and reducing the observations made by members of the Jupiter Section of the British Astronomical Association continues. In 1941 April the thirtieth Report of the Section, dealing with the apparitions of 1934, 1935 and 1936, was presented to the Council and was published by the Association in August. The preparation of the thirty-first Report is well advanced and its early completion is anticipated.

The 12¼-inch Linscott mirror has been refigured by Mr. F. J. Hargreaves. The original figure was very satisfactory, but the polish in places was greatly at fault. The performance of the mirror is now exceptionally fine from every point of view.

Mr. F. J. Sellers's Observatory, Muswell Hill, London

Daily observations of the Sun were made whenever possible with telescope, spectroscope and spectrohelioscope until 1940 September 11, when the bombardment of London made it advisable to dismantle and store the optical parts of the instruments in a safer place. Records of the observations have been summarized in the quarterly reports in the *B.A.A. Journal*. It is hoped to begin observational work again in the near future, with particular attention to radial velocities of dark flocculi accompanying and, if detectable, *preceding* bright chromospheric eruptions.

Wolsingham Observatory, Tow Law, Co. Durham
(*Observer, Mr. W. Milburn*)

Double star catalogue work has been continued. Micrometric measures of certain known pairs in the B.D. zones +25° to +40° have been made with the 24-inch Calver Reflector.

The 5-inch refractor has been chiefly used for visitors.

REPORTS ON THE PROGRESS OF ASTRONOMY

INTERSTELLAR MATTER

Evidence suggesting the presence of significant quantities of matter in interstellar space is afforded by the following observations:—

(*a*) The bright diffuse galactic nebulæ and the conspicuous dark nebulosities usually associated with them.

(*b*) Certain dark markings in the sky which were formerly explained on the basis of stellar distribution, but which are now attributed to the presence of obscuring matter.

(*c*) The presence of a zone of avoidance in the galactic plane where no globular clusters nor spiral nebulæ are visible.

(*d*) The dark band usually associated with spiral nebulæ when seen edge on.

(*e*) Departures from the inverse square law of brightness in the case of certain stars whose distances and intrinsic luminosities are known with reasonable certainty.

(*f*) The reddening of stars of early type which are normally white or blue in colour.

(*g*) The presence in stellar spectra of absorption lines of various widths which cannot reasonably be attributed either to the atmospheres of the stars or the Earth's atmosphere.

Two kinds of interstellar matter are known to exist: (1) Matter in gaseous form, first recognized as such by the observation of emission lines in the diffuse nebulæ * and by the appearance of interstellar absorption lines due to known atoms in the spectra of stars †, and (2) solid particles, first recognized as such by the spectra of "reflection type" nebulæ.‡ In this report the two types of matter are dealt with separately, the solid particles being taken up first.

The Solid Particles

General Absorption.—An initial approach to the problem of general absorption is provided by the data of Seares §, Van de Kamp ||, Shapley ¶ and Hubble ** on the distribution of extra-galactic nebulæ in galactic latitude. Counts of the nebulæ were shown to vary with the latitude according to a cosecant law, indicating the presence of a flattened stratum of absorbing material with a plane coincident with that of the galaxy and a total absorption of photographic light from pole to pole of from 0·5 to 0·8 stellar magnitudes. A strict interpretation of the cosecant law would imply uniform density, but this result is a consequence of taking statistical averages, and it is known that the actual distribution of material is very irregular.

The best modern determinations of the average coefficient of general photographic absorption are those of Trumpler and Joy. Trumpler †† made use of the apparent diameters of open clusters to estimate their distances and employed slit spectra of individual stars to estimate their spectral types and absolute magnitudes. On the basis of the deviation of the brightness of individual stars from the inverse square law he derived an average value of the general photographic absorption of 0·67 mag. per

* Huggins, *Phil. Trans. Roy. Soc.*, 1864; *Proc. Roy. Soc.*, **20**, 373, 1872; Secchi, *Comptes Rendus*, **60**, 543, 1865.

† Hartmann, *Ap. J.*, **19**, 268, 1904.

‡ Slipher, *Lowell Obs. Bull.*, No. 55, 1912.

§ Seares, *Ap. J.*, **62**, 168, 1925.

|| Van de Kamp, *A. Journ.*, **42**, 97, 1932.

¶ Shapley, *Proc. Nat. Acad. Sci.*, **19**, 389, 1933.

** Hubble, *Ap. J.*, **79**, 8, 1934; Mt. W. Cont. 485.

†† Trumpler, *Lick O. Bull.*, **14**, 154, 1930; *P.A. Soc. Pac.*, **42**, 214, 267, 1930.

kiloparsec. Joy's * determination was based on a study of the radial velocities and periods of faint galactic Cepheids. He determined the distances from the galactic rotation effect in radial velocities and their absolute magnitudes from the well-known period luminosity relation. His value of 0·85 mag. per kiloparsec is probably the most reliable one available at the present time.

From the above value of the absorption coefficient the total absorption from pole to pole of 0·5 to 0·8 mag. due to Van de Kamp and Hubble may be used to calculate the effective thickness of the absorbing stratum. For a coefficient of 0·85 mag. per kiloparsec the thickness of the stratum is of the order of 1000 parsecs, although it is by no means certain that a value of the absorption coefficient obtained from observations of objects close to the galactic plane is immediately applicable to optical paths which involve angles which range from 10° to 90°. The extent of the absorbing stratum in the galactic plane is uncertain. It seems reasonable to suppose that it is co-extensive with the galaxy as a whole, although on the basis of present observations the possibility that it is a local phenomenon cannot be entirely excluded.

Selective Absorption.—The existence of selective absorption is known from the reddening of distant stars and clusters, but its correlation with distance is rendered uncertain by the small average values of the quantities to be measured and the irregularity of distribution of the material producing the observed colour excess. Numerical values depend on photo-electric measures of the colours of stars by Elvey † and Hall ‡ on similar observations of extra-galactic nebulæ §, globular clusters ‖ and B-type stars ¶ by Stebbins and his associates, Huffer and Whitford, and on photographic investigations of the colours of stars by Trumpler **, Seares ††, Oort ‡‡, Schalén §§, Zug ‖‖ and Smith.¶¶

For such parts of the absorbing stratum as are involved in colour observations of the extra-galactic nebulæ the colour excess is small, being about 0·1 of the value of the general photographic absorption. On the basis of the coefficient of general absorption by Joy this would correspond to a colour excess of 0·08 mag. per kiloparsec. For colour observations of objects of low galactic latitude within the stratum much higher values are sometimes observed. In general, however, the results are puzzling and uncertain, since relatively nearby stars are sometimes strongly reddened while distant objects as far away as 2000 parsecs may show a scarcely measurable colour excess. It seems clear that overlapping clouds with occasional clear patches between are involved, and for objects at such distances as the bulk of the B-type stars so far observed it seems meaningless to state a definite value for the coefficient of selective absorption, which will be applicable to all regions of the galaxy. Values appear to range from 0·08 mag. to 0·35 mag. per kiloparsec, and it seems probable that still higher values prevail in limited regions of space since none of the clouds which produce strong reddening is near the Sun. Seares *** considers that the selectively absorbing clouds float within the general stratum of absorbing material, and outline by their strong extinction the zone of avoidance of extra-galactic nebulæ and globular clusters.

Spectrophotometric measures of reddened B stars by Trumpler †††, Struve, Keenan

* Joy, *Ap. J.*, **89**, 356, 1939.
† Elvey, *Ap. J.*, **74**, 298, 1931.
‡ Hall, *Ap. J.*, **85**, 145, 1937.
§ Stebbins and Whitford, *Ap. J.*, **86**, 247, 1937.
‖ Stebbins and Whitford, *Ap. J.*, **84**, 132, 1936.
¶ Stebbins, Huffer and Whitford, *Ap. J.*, **91**, 20, 1940; Mt. W. Cont., 621.
** *Loc. cit.*
†† Seares, *P.A. Soc. Pac.*, **43**, 53, 57, 1931; *Proc. Nat. Acad. Sci.*, **22**, 327, 1936.
‡‡ Oort, *B.A.N.*, **8**, 233, 1938.
§§ Schalén, *Upsala Medd.*, No. 58, 1934.
‖‖ Zug, *Lick O. Bull.*, **16**, No. 454, 1933.
¶¶ Smith, *Lick O. Bull.*, **18**, 39, 1937.
*** Seares, *P.A. Soc. Pac.*, **52**, 3, 1940.
††† *Loc. cit.*

and Hynek *, Rudnick †, and Greenstein ‡, using photographic methods, and by Hall § and Stebbins and Whitford ‖ using photo-electric methods, have indicated that to a first approximation the selective absorption coefficient is inversely proportional to wave-length (λ^{-1} law) over the range of spectrum ordinarily observed. The λ^{-1} law of absorption leads to the following relation between general photographic absorption and colour excess :—

$$\frac{A_{pg}}{E} = \frac{\lambda_{pg}^{-1}}{\lambda_{pg}^{-1} - \lambda_{v}^{-1}}$$

where A_{pg} is the photographic absorption and E the colour excess. For $\lambda = 4250$ A. and $\lambda = 5290$ A., the wave-lengths corresponding to the photographic and visual system of magnitudes,

$$\frac{A_{pg}}{E} = 5{\cdot}08.\text{¶}$$

The observed values of this ratio as derived from measures of photographic absorption and colour excess range from 9·0 ** to 3·2 ††, and the interpretation of their deviation from the value predicted from the spectrophotometric measures is by no means clear. It may be pointed out, however, that the spectrophotometric measures are not yet sufficiently numerous or precise to give any positive assurance that the λ^{-1} law holds universally throughout galactic space and the larger values of the ratio can logically be attributed to the presence of a proportion of material which absorbs non-selectively.

Sizes of the Particles.—The conclusion that the general and selective absorption are due to scattering by solid particles rather than gases (inferred in the preceding paragraphs of this section) follows from a consideration of the relative masses of gaseous and solid particles required to produce the observed effects. Trumpler ‡‡ and others have pointed out that the density of gaseous material required to produce the observed absorption coefficients is hundreds of times greater than the density of the galaxy in the neighbourhood of our Sun due to both stars and interstellar material. (The best modern value of the density of the galaxy due to Oort §§ is 0·09 solar masses per cubic parsec.) The efficiency of scattering by solid particles depends upon their size and chemical constitution, but it has been known for many years ‖‖ that solid particles of the order of the wave-length of light in size are capable of producing the observed general absorption without even approaching the limits of density set by Oort's result.

More specific estimates of the order of size of the particles are obtained by Struve ¶¶ as follows. Oort's limit referred to above requires an average particle diameter smaller than 0·01 cm. in order to account for the observed general absorption. Diameters between 0·01 cm. and 0·001 cm. are excluded by the absence of bright diffraction rings surrounding stars imbedded in nebulosity, so that the average diameter must be smaller than 0·001 cm. On the other hand, the fact that the colours of reflection nebulæ are very little bluer than the stars which illuminate them, and the absence of polarization phenomena associated with them, indicates that the average particle size should not

* Struve, Keenan and Hynek, *Ap. J.*, **79**, 1, 1934.
† Rudnick, *Ap. J.*, **83**, 394, 1936.
‡ Greenstein, *Ap. J.*, **87**, 151, 1938.
§ *Loc. cit.*
‖ *Ap. J.*, **91**, 20, 1940.
¶ This ratio is quite sensitive to the values adopted for the effective wave-lengths, and quoted values range from 4·6 to 5·7.
** Stebbins, *P.A. Soc. Pac.*, **53**, 84, 1941.
†† Popper and Seyfert, *Ap. J.*, **93**, 461, 1941.
‡‡ *Loc. cit.*
§§ Oort, *B.A.N.*, **6**, 249, 1936; *Ann. d'Ap.*, **1**, 71, 1938.
‖‖ Russell, *Proc. Nat. Acad. Sci.*, **8**, 115, 1922.
¶¶ Struve, *Ann. d'Ap.*, **1**, 143, 1938.

be smaller than 10^{-5} cm. Finally, the application by Schalén *, Greenstein † and others of Mie's ‡ theory of the scattering of light by small particles to the λ^{-1} law of absorption for reddened B stars results in an average size for the scattering particles of slightly greater than 10^{-5} cm. Actually it is not to be expected that the particles will be of uniform size, and present studies of the matter aim rather at deducing the frequency distribution of particle diameters. Greenstein has discussed this aspect of the subject in considerable detail, and suggests a frequency distribution which varies as $a^{-3\cdot8}$ where a is the particle diameter with a mean density for the absorbing material of 10^{-25} gm. per c.c. Progress in this branch of the subject requires the extension of the spectrophotometric measures to longer wave-lengths, while any information regarding the chemical constitution of the solid particles which might conceivably be given by the appearance of bands or other features appearing in the spectra of stars would be extremely valuable.

Gases in Interstellar Space

Atomic Emission Lines and the Diffuse Nebulæ.—The presence of gaseous material in certain diffuse nebulæ has been known for many years by the atomic emission lines in their spectra. The Orion nebula is the best known example of this type, and its spectrum is characterized by lines due to *H*, *He*, *O* and *N* in various stages of ionization. Dark nebulosity is also a feature of this nebula, and since a continuous spectrum accompanies the bright lines of this and a number of other diffuse nebulæ § it is reasonably certain that there is some solid material in the form of fine particles mixed with the gases. The so-called "reflection nebulæ," which exhibit absorption spectra similar to the stars in their immediate neighbourhood, do not show emission lines, and the investigations of Hubble || have suggested the reason to be the absence of sufficiently early-type stars to excite an emission line spectrum. It thus seems a reasonable presumption that all diffuse nebulæ consist of dust and gas, though the proportions of gaseous and solid material are not always the same.

One of the most interesting problems regarding diffuse nebulæ is whether they are of purely local significance or whether they are condensations of a type of material which is generally distributed throughout interstellar space. Evidence pointing to a general distribution of solid particles throughout interstellar space has been given in the previous section. New evidence regarding the distribution of interstellar gases has been provided by the recent remarkable results obtained by Struve and Elvey ¶ at the McDonald Observatory. Making use of a nebular spectrograph consisting of two prisms and an *f* 1 Schmidt camera in conjunction with a narrow plane mirror at an effective distance of 150 feet as a slit, they have discovered emission lines due to *H*, *O* II, *N* II and *O* III in many parts of the sky not hitherto associated with bright nebulosity. The location in the sky of the regions showing bright lines was such as to indicate that they were associated with groups of O-type stars. The distribution of emission within the regions suggested a stratification somewhat similar to that observed in the planetary nebulæ. When *O* III appears it is always near the centre of the emitting region, while *H* and *O* II and *N* II extend to greater distances and are sharply bounded on the outside. The lines due to oxygen and nitrogen are the well-known "nebular" type of resonance lines due to forbidden transitions between the two lowest levels of the atom. The average extent of the regions of nebulosity is of the order of several hundred parsecs. The limitation of the emission to a sharply bounded region surrounding a group of

* Schalén, *Ann. Upsala*, 1, 2, 1939; *Ann. d'Ap.*, 1, 60, 1938.
† Greenstein, *H.C.*, 422, 1937.
‡ Mie, *Ann. d'Phys.*, 25, 377, 1908.
§ Slipher, *P.A. Soc. Pac.*, 31, 212, 1919; *Ap. J.*, 87, 559, 1938.
|| Hubble, *Ap. J.*, 56, 162, 192.
¶ Struve and Elvey, *Ap. J.*, 87, 559, 1938; Struve, *Journ. Wash. Acad. Sci.*, 31, 217, 1941.

O-type stars is interpreted by Struve and Strömgren as a consequence of the absorption of short wave-length radiation in the process of ionization rather than to a limitation in the distribution of the gases responsible for emission.

These observations strongly suggest that material similar to that found in the diffuse nebulæ is distributed throughout the extent of the galaxy and requires only an appropriate source of ultra-violet radiation to make it luminous. If this is the case, any information gained regarding the chemical composition of the diffuse nebulæ is applicable to interstellar space as a whole, and it is reasonably certain that all atoms known to be present in the diffuse nebulæ are also constituents of interstellar space even though their lines may be too faint to be detected by the methods outlined above.

Atomic Absorption Lines.—For many years the H and K lines of calcium discovered by Hartmann * and the two sodium D doublets discovered by Miss Heger † were the only lines appearing in stellar spectra which were known to be due to interstellar matter. Recently discoveries by Dunham and Adams ‡ and Dunham § have added lines due to *Ti* II, *Ca* I and *K* I, while in a paper which has just appeared Dunham and Adams ‖ have reported the definite identification of lines due to *Fe* I. Table I contains a list

TABLE I

Interstellar Lines of Atomic Origin

Absorption Lines			Emission Lines		
Atom	λ	Multiplet	Atom	λ	Multiplet
Na I	3302·38	$3^2S - 4^2P^0$	*H*	4340·48	$2^2P^0 - 5^2D$
Na I	3302·98	$3^2S - 4^2P^0$	*H*	4861·34	$2^2P^0 - 4^2D$
Na I	5889·98	$3^2S - 3^2P^0$	*H*	6562·81	$2^2P^0 - 3^2D$
Na I	5895·94	$3^2S - 3^2P^0$	*O* II	3726·12	$a^4S^0 - a^2D^0$
K I	7664·88	$4^2S - 4^2P^0$	*O* II	3728·91	$a^4S^0 - a^2D^0$
K I	7698·98	$4^2S - 4^2P^0$	*O* III	4958·91	$2p^3P - 2p^1D$
Ca I	4226·74	$4^1S - 4^1P^0$	*O* III	5006·84	$2p^3P - 2p^1D$
Ca II	3933·68	$4^2S - 4^2P^0$	*N* II	6548·1	$2p^3P - 2p^1D$
Ca II	3968·49	$4^2S - 4^2P^0$	*N* II	6583·6	$2p^3P - 2p^1D$
Ti II	3072·97	$a^4F - z^4D^0$			
Ti II	3229·18	$a^4F - z^4F^0$			
Ti II	3241·97	$a^4F - z^4F^0$			
Ti II	3383·78	$a^4F - z^4G^0$			
Fe I	3719·95	$a^5D - z^5F^0$			
Fe I	3859·92	$a^5D - z^5D^0$			

of the atomic lines so far identified. All the interstellar absorption lines which have been identified correspond to transitions from the lowest atomic energy level of the atom, and in the case of *Ti* II, where the lowest term (^4F) consists of four sublevels, only lines arising from the lowest sublevel have been observed. This leads to the conclusion that under the conditions of interstellar space, sublevels above the normal state are depopulated by forbidden transitions.¶ A similar situation exists in connection with certain molecular lines to be discussed in the next paragraph.

Absorption Lines due to Molecules.—The fact that all interstellar atomic absorption lines arise from the lowest level of the atom and that even the sublevels of extremely low excitation potential are not populated, suggested that any absorption by molecules in interstellar space would involve transitions from only a few of the lowest rotational

* Hartmann, *Ap. J.*, **19**, 268, 1904.
† Heger, *Lick O. Bull.*, **10**, 141, 1919.
‡ Dunham and Adams, *A.A.S.*, **39**, 5, 1937.
§ Dunham, *P.A. Soc. Pac.*, **49**, 26, 1937.
‖ Dunham and Adams, *P.A. Soc. Pac.*, **53**, 341, 1941.
¶ Dunham, *Nature*, **139**, 246, 1937.

levels of the normal state of the molecule (for lines so far observed only the two lowest rotational states are involved). On this basis each "band" as observed in laboratory or stellar spectra would consist of one or more isolated narrow lines which could only be distinguished from atomic absorption by measurements of wave-length and, in some cases, of relative intensity.

McKellar * has determined from laboratory data the wave-lengths to be expected from a number of such common molecules as would likely be present in interstellar space, and with the aid of observations by Adams † four lines due to *CH*, one of which

TABLE II

Interstellar Absorption Lines of Molecular Origin

Molecule	Line	Interstellar λ	Lab. λ
CH	R(1)	4300·34	4300·31
CH	$^{P}Q_{12}(1)$	3890·25	3890·23
CH	$Q(1)+{}^{Q}R_{12}(1)$	3886·44	3886·39
CH	$R_2(1)$	3878·81	3878·77
CN	P(1)	3875·77	3875·77
CN	R(0)	3874·62	3874·61
CN	R(1)	3874·02	3874·00
CH^+	R(0)	4232·58	4232·57
CH^+	R(0)	3957·72	3957·71
CH^+	R(0)	3745·33	3745·30

was previously noted by Swings and Rosenfeld ‡ and three due to *CN*, have been definitely identified. More recently, three additional lines observed by Adams and Dunham have been shown to be due to CH^+ by Douglas and Herzberg.§ The wave-lengths and identifications of these lines have been given in Table II. The molecular lines so far observed are very faint, and it seems probable that greater telescopic power and higher dispersion or spectrographic resolution would result in many more discoveries.

Unidentified Interstellar Absorption Lines.—Interstellar lines as yet unidentified fall into two classes: (1) Narrow lines which are similar in character to lines already identified and which are presumably of similar origin. A list of such lines is given in the second column of Table III, and it seems reasonably certain that these lines are due to absorption by gases in the form of atoms or molecules. (2) Lines which have a definitely diffuse character which differentiate them sharply from the interstellar lines referred to above. All of these lines were discovered by Merrill ||, and all but two are in the visible region. One line (λ 4430) is of the order of 60 angstroms in width, and evidence pointing to an interstellar origin has been presented by Beals and Blanchet ¶ and Miss Sherman.** Present knowledge of the physical conditions of interstellar space make it difficult to account for these lines as due to absorption by molecules of gas, although Swings, in a recent paper kindly communicated in advance of publication, has suggested as a possibility that homonuclear molecules such as C_2 and O_2 may be so distributed among rotational states as to give rise to unresolved features of considerable width. The only alternative explanation appears to be absorption by solid particles, and such a suggestion is given credence by a fair correlation of the intensities of the

* McKellar, *P.A. Soc. Pac.*, **52**, 307, 1940; *P. Dom. Ap. O.*, **7**, 15, 1941 (in press).
† Adams, *Ap. J.*, **93**, 11, 1941.
‡ Swings and Rosenfeld, *Ap. J.*, **86**, 483, 1937.
§ Douglas and Herzberg, *Ap. J.*, **94**, 381, 1941.
|| Merrill and Wilson, *Ap. J.*, **87**, 9, 1938.
¶ Beals and Blanchet, *M.N.*, **98**, 398, 1938.
** Sherman, *Ap. J.*, **90**, 630, 1939.

diffuse lines with space reddening.* There is as yet no confirmatory evidence from laboratory spectra to support such a hypothesis, but the absorption spectra of common gases in the solid form are very little known, and until more data of this kind are available the matter must remain in a state of uncertainty.

TABLE III

Unidentified Interstellar Lines

Diffuse Lines		Sharp Lines	
λ	Int.	λ	Int.
4430·6*	10	3579·04 †	0
4760 ‡		3934·3 §	0
5780·55	3		
5797·13	1		
6202·99	1		
6269·99	1		
6283·91	6		
6613·9	2		

* This indication of intensity reflects the equivalent width of this line. The actual existence of the line is always difficult to detect because of its great width.

† May be due to 3·0 band of CH^+ system.

‡ A broad feature tentatively identified by Merrill as an interstellar line 3, 0. (Private communication.)

§ May be due to *NaH* (*Ap. J.*, 93, 11, 1941).

Motions of Interstellar Gases.—Present knowledge of the motions of interstellar gases depends largely on radial velocity measures of lines due to Ca^+ and *Na*. Individual velocities are due to many sources, since the interstellar velocity is a by-product of most velocity measures of early-type stars. The largest single body of data is due to Plaskett and Pearce †, although notable contributions have since been made by the Mount Wilson observers ‡, who included both calcium and sodium lines in their measurements. Analyses of these velocities carried out by Plaskett and Pearce § and by Merrill and Sanford ‖ have led to the following conclusions: (1) The velocities of calcium and sodium lines are closely similar, and cases where discrepancies occur can usually be traced to blends with stellar calcium lines. (2) The residual radial velocities after the solar component has been removed are largely influenced by galactic rotation, and show the familiar double wave relation

$$v = \bar{r}A \sin 2(l - l_0) \cos^2 b.$$

Plaskett and Pearce's solutions led to the interesting result that the mean distances for the interstellar lines came out almost exactly one-half those for the corresponding stars. A strict interpretation of this result leads to the conclusion that the absorbing material is uniformly distributed between the star and the observer. There is every reason to believe that this conclusion is statistically accurate although there is almost certainly some local irregularity of distribution. (3) A study of the residuals in solutions for galactic rotation indicates the presence of peculiar motions in the interstellar medium having maximum values of the order of 20 km./sec. These observations suggest some irregularity of motion and distribution which may be referred to as turbulence. Further confirmation of the existence of turbulent motions is provided by the observation by Beals ¶, later confirmed by the Mount Wilson observers, of interstellar lines showing

* Merrill and Wilson, *Ap. J.*, 87, 9, 1938 ; Sherman, *Ap. J.*, 90, 630, 1939.

† Plaskett and Pearce, *P. Dom. Ap. O.*, 5, 1, 99, 1935.

‡ Merrill, Sanford, Wilson and Burwell, *Ap. J.*, 86, 274, 1937.

§ Plaskett and Pearce, *op. cit.*, p. 168.

‖ Merrill and Sanford, *Ap. J.*, 87, 118, 1938; *Ap. J.*, 85, 73, 1937.

¶ Beals, *Ap. J.*, 87, 568, 1938.

complex structure, and by the older observations by Campbell and Moore * of irregular motions in the Orion nebula.

Relation between Interstellar Line Intensity and Distance.—Investigations by Struve † and by Plaskett and Pearce ‡ on the basis of eye estimates of line intensity first indicated the existence of a relationship between the distance of a star and the intensity of interstellar lines appearing in its spectrum. Later, spectrophotometric measures on interstellar line intensity became available as a result of the work of Beals §, Williams ||, and Merrill, Sanford, Wilson and Burwell. ¶ For the purpose of correlating these line intensities with distance there are available a few trigonometrical parallaxes of nearby stars, some proper motion data, the distances of a few clusters derived by Trumpler's method and the powerful method of deriving the distances of groups of stars provided by the theory of galactic rotation. Curves relating intensity and distance have been published by Williams **, Beals ††, Wilson and Merrill ‡‡ and by Sanford. §§ Agreement between different curves is reasonably good although there is evidence of systematic differences between the Victoria and Mount Wilson measures. The recent compilation by Evans |||| constitutes an excellent review of the present situation, and he gives the following straight-line relation between intensity and distance:—

$$r \text{ (kiloparsecs)} = 2{\cdot}38\ \mathrm{D}$$
$$r \text{ (kiloparsecs)} = 3{\cdot}00\ \mathrm{K}.$$

Here r is the distance, D is the mean equivalent width in angstroms of the two sodium D lines, while K is the corresponding equivalent width for *Ca* II K. While the errors are estimated to be of the order of 20 per cent., the use of such a relation probably provides the most accurate method now available for estimating the distance of an individual early-type star.

Ionization in Interstellar Space.—The first calculation of the ionization of interstellar space was made by Eddington. ¶¶ He pointed out that although the total energy density of radiation in interstellar space corresponds to a temperature of 3·2° K, a body which absorbs selectively in the short wave-length region may attain a very much higher temperature owing to the richness of starlight in radiation of high frequencies. Assuming the mechanism of selective absorption to be the photo-electric ionization of atoms with ionization potentials in the range 5–10 volts, he derived a temperature of 10,000° K *** for atoms capable of absorbing in this range. Making use of this value of the temperature in connection with the appropriate dilution factor he calculated the ionization of sodium and calcium atoms from the equation

$$\frac{1-x}{x} = N_e \left(\frac{h^2}{2\pi m R T} \right)^{2/3} e^{h\nu/RT}, \qquad (1)$$

where x is the proportion of ionized atoms, N_e is the number of free electrons per c.c., T is the temperature and the other constants of the equation have their usual significance.

* Campbell and Moore, *P. Lick O.*, **13**, 96, 1918.
† Struve, *Ap. J.*, **67**, 353, 1928.
‡ *Loc. cit.*
§ Beals, *M.N.*, **93**, 585, 1933; **94**, 663, 1934; **96**, 661, 1936.
|| Williams, *Ap. J.*, **79**, 280, 1934.
¶ *Loc. cit.*
** *Loc. cit.*
†† Beals, *P. Dom. Ap. O.*, **6**, 333, 1937.
‡‡ Wilson and Merrill, *Ap. J.*, **86**, 129, 1937.
§§ Sanford, *Ap. J.*, **86**, 173, 1937.
|||| Evans, *Ap. J.*, **93**, 275, 1941.
¶¶ Eddington, *Internal Constitution of the Stars*, Cambridge University Press, 1926.
*** Swings (*M.N.*, **97**, 212, 1937) has since pointed out that the corresponding temperature for selective absorption in the region beyond 10,000 A. (involved in transitions between the lowest rotational states of molecules) is of the order of 5° K.

Results indicated the following relationships between the numbers of atoms in neutral and ionized states, triple ionizations of *Ca* and double ionizations of *Na* being negligible:

$$\frac{Ca\,\mathrm{I}}{Ca\,\mathrm{II}} = \frac{1}{300{,}000} \qquad \frac{Ca\,\mathrm{II}}{Ca\,\mathrm{III}} = \frac{1}{400} \qquad \frac{Na\,\mathrm{I}}{Na\,\mathrm{II}} = \frac{1}{1{,}000{,}000}.$$

A later investigation by Gerasimovič and Struve * led to an essentially similar result for the state of ionization of sodium and calcium atoms. It had been known for many years that the intensities of interstellar *Na* I and *Ca* II lines were of the same order of magnitude, and in 1933 Beals † carried out spectrophotometric measures of lines in the spectra of ξ Persei and 9 Camelopardalis which showed that the equivalent widths in km./sec. of the sodium lines were somewhat greater than the corresponding lines of *Ca* II. These results, interpreted in terms of the above figures for ionization, would require a 300-fold greater abundance of sodium than calcium, a result difficult to accept in view of the known fact that, terrestrially, sodium is only four times as abundant as calcium.

Eddington ‡ later suggested that the approximate equality of the intensities of sodium and calcium lines was a consequence of saturation in a flat-bottomed profile due to the Doppler broadening produced by galactic rotation. Such a mechanism would result in a definite relation between intensity and velocity which was shown by Beals §, and later by Sanford || and by Wilson and Merrill ¶, to be non-existent except for the most distant stars. Their observations suggested rather that the width of the interstellar lines was largely due to turbulent motions in the absorbing medium. While this conclusion would not of itself entirely rule out the argument based on saturation, the observation by Beals ** that the intensities of the sodium lines in certain nearby stars were of the order of twice those of calcium could not be accounted for on this basis.

Barring an excessive abundance of sodium in interstellar space it thus appeared that some important factor had been left out of the calculations and that the actual state of ionization of sodium and calcium in interstellar space was much lower than had previously been supposed. Such a conclusion received strong support from the discovery by Dunham †† of an interstellar line at λ 4226 due to *Ca* I in the spectrum of χ Orionis. On the basis of measured intensities of lines due to *Ca* I and *Ca* II in χ Orionis in connection with known values of the atomic constants, Dunham ‡‡ derived the following result for the relative numbers of atoms in the neutral and singly ionized states:—

$$\frac{Ca\,\mathrm{I}}{Ca\,\mathrm{II}} = \frac{1}{3{,}500}.$$

Making use of this ratio in an equation of the same general form as equation (1), and using values of the density and quality of interstellar radiation which were similar to those adopted by Eddington except that he made a correction for the value of selective absorption by solid particles, Dunham found for the density of free electrons in interstellar space a value of the order of 10 per c.c. This high value of N_e was difficult to explain if the ionization of sodium and calcium (or indeed of other common atoms in terrestrial relative abundance) were the source of the free electrons, and this gave rise to another theoretical difficulty to add to those already encountered.

What may prove to be a solution of the difficulty is found in the previously mentioned §§

* Gerasimovič and Struve, *Ap. J.*, **69**, 1, 1929.
† Beals, *M.N.*, **93**, 585, 1933.
‡ Eddington, *M.N.*, **95**, 2, 1934.
§ Beals, *M.N.*, **96**, 661, 1936.
|| Sanford, *Ap. J.*, **86**, 126, 1937.
¶ Wilson and Merrill, *Ap. J.*, **86**, 44, 1937.
** *Loc. cit.*
†† Dunham, *P.A. Soc. Pac.*, **49**, 26, 1937.
‡‡ Dunham, *Proc. Amer. Phil. Soc.*, **81**, 277, 1939.
§§ Struve and Elvey, *Ap. J.*, **87**, 559, 1938; Struve, *Journ. Wash. Acad. Sci.*, **31**, 217, 1941.

discovery by Struve and his collaborators of hydrogen emission lines in extensive areas of the sky not associated with visible nebulosity. Struve * and Strömgren † have discussed the observations from a theoretical point of view, and conclude that most of the hydrogen in the emission regions must be ionized. If we apply to interstellar space modern ideas concerning the abundance of hydrogen in the stars, then a great majority of the interstellar atoms will be hydrogen, and if most of these atoms are ionized they will provide a source of free electrons not contemplated in the earlier calculations.

Making use of values of N_e which range from 1 to 10 per c.c. and which correspond to the order of density derived by Strömgren for interstellar hydrogen, Struve and Dunham have derived values of the abundance of sodium relative to calcium which range from 17 to 7, and Struve expresses the opinion that the discrepancy between theory and observation represented by the relative intensities of *Na* I and *Ca* II lines has now been largely removed. Without dissenting from an opinion which is supported by the best recent observations we may point out that there remain a few difficulties which may delay a final decision on this point. These include: (1) The restriction of hydrogen emission to relatively limited regions, suggesting that a large proportion of interstellar hydrogen remains unionized; (2) the rather large density of interstellar space required by the values of N_e given above; and (3) lack of complete knowledge concerning the absorbing qualities of the interstellar medium due to solid particles, atoms and molecules in the critical short wave-length regions involved in the ionization of calcium and sodium.

Density of Interstellar Matter.—Estimates of the density of interstellar matter are necessarily subject to great uncertainty. Dynamical considerations give an upper limit of 6×10^{-24} gm. per c.c. for the galaxy as a whole, but Oort's recent discussion indicates that the partition of mass between visible stars and invisible interstellar matter cannot be estimated with any degree of accuracy. He does suggest, however, that interstellar matter is probably a small fraction of the whole, and this implies a value of the order of 10^{-24} gm. per c.c. for the interstellar material in agreement with an estimate made by Eddington nearly twenty years ago.

Dunham has given 5×10^{-25} gm. per c.c. as the mean space density of meteors on the basis of the number entering the Earth's atmosphere per second, but this density may be a characteristic of the solar system. Dunham estimates the density of solid material responsible for absorption as 10^{-26} gm. per c.c. Greenstein's estimate of the space density of solid particles based on an extrapolation of the observed frequencies of hyperbolic meteors (meteors from outside the solar system) is 2×10^{-25} gm. per c.c. These estimates are probably the best available at the present time, but they can hardly be regarded as definite enough to form the basis of a judgment of the distribution of interstellar mass as between solid particles and gases.

Recent estimates of the density of interstellar gases made by Dunham and Struve on the basis of absorption and emission line intensities are given in Table IV. This

TABLE IV

Density of Gases in Interstellar Space

Atom	Density (Dunham)	Density (Struve)
Hydrogen	$1{\cdot}7 \times 10^{-23}$	$2{\cdot}7 \times 10^{-24}$
Oxygen	...	$2{\cdot}3 \times 10^{-26}$
Sodium	4×10^{-27}	4×10^{-29}
Potassium	7×10^{-28}	...
Calcium	7×10^{-28}	7×10^{-30}
Titanium	8×10^{-30}	...
CH	2×10^{-29}	....
CN	$1{\cdot}5 \times 10^{-29}$	...

* Struve, *Proc. Nat. Acad. Sci.*, **25**, 36, 1939.

† Strömgren, *Ap. J.*, **89**, 526, 1939.

table suggests that the interstellar gas consists mainly of hydrogen and that its estimated density approaches or exceeds Oort's limit for the density of the galaxy as a whole. Most astrophysicists would be reluctant to accept the idea that the mass of the galaxy is mainly in the form of interstellar gas, but if we are to place any faith in these estimates such a possibility cannot be entirely excluded. The figures for the density of hydrogen depend on the values of N_e given in a preceding paragraph, and any change in present ideas regarding ionization would have an effect on the results.

Conclusion.—As expected in an active branch of astrophysics many of the conclusions stated in this review are of a tentative character. This is as it should be, since nothing is more likely to hinder the further development of the subject than the premature general acceptance of a result whose validity has not been fully demonstrated. The past two decades have seen truly remarkable advances in knowledge of interstellar matter, and it appears that some of the most fundamental problems may be on the verge of final solution. Until that point is reached, however, it is highly desirable to emphasise the "open" character of the subject and the possibility that new observations and new theoretical ideas may reverse conclusions which time has clothed with a considerable degree of authority.

In the preparation of this report it is hoped that the references include most of the important papers of recent years. Each paper quoted has an extensive list of references attached to it and no attempt has been made to compile a complete bibliography. The literature available to the writer has been somewhat limited, and if any source has been neglected it has been done unintentionally. Attention of the reader may usefully be directed to general reviews by Seares *, Struve † and Eddington ‡, and to the papers given at the *Première Conférence International d'Astrophysique.* § Recent papers not specifically mentioned in this review comprise the following list:—

Wilson, "Galactic Rotation and Absorption," *Ap. J.*, **92**, 170, 1940.

O'Keefe, "Distances of Reddened B Stars," *Ap. J.*, **94**, 353, 1941.

Spitzer, "Dynamics of the Interstellar Medium," *Ap. J.*, **94**, 232, 1941.

Stebbins, Huffer and Whitford, "Selective Absorption in Space near the Sun," *Ap. J.*, **94**, 215, 1941.

Adams, "Some Results with the Coudé Spectrograph of the Mount Wilson Observatory," *Ap. J.*, **93**, 11, 1941.

Rosseland, "Absorption of Light in Space," *M.N.*, **98**, 301, 1938.

"A Summary of the Symposium on Interstellar Lines at the Yerkes Observatory," *Pop. Ast.*, **49**, 513, 1941.

Van Rhijn, "The Absorption of Light in Interstellar Galactic Space and the Galactic Density Distribution," *Groningen Pub.*, No. 47, 1936.

C. S. BEALS

Dominion Astrophysical Observatory,
Victoria, B.C., Canada:
1942 *January* 9.

* Seares, *P.A. Soc. Pac.*, **52**, 3, 1940.
† Struve, *Journ. Wash. Acad. Sci.*, **31**, 217, 1941.
‡ Eddington, *The Observatory*, **60**, 99, 1937.
§ *Ann. d'Ap.*, **1**, 6–260, 1938.

COMETS

Since the last report on Comets in *M.N.*, **100**, 327, 1940, which included comets observed up to the end of 1939, seven new comets and three expected periodic comets have been detected. As most of the information has been derived from *H.C.O. Announcement Cards*, many of which are delayed considerably in the post and some of which have been lost in transmission, certain data are missing in some cases. This will explain the absence of precise information regarding the time and place of discovery for one or two comets. In addition, some of the orbits which are given may not be the most recent.

Comet Cunningham was discovered by Cunningham on plates taken at Oak Ridge on 1940 September 5. Several other plates taken between August 25 and September 15 also showed the comet, which appeared to be about magnitude 12, with a strong nucleus and a tail extending 2′ southwards. In the early part of 1941 it was well observed, and in this country a number of the members of the British Astronomical Association kept it under observation for some time. Its magnitude on January 2 was estimated to be about 4·7. Mr. Cunningham has undertaken to compute a definitive orbit of this comet.

Comet Okabayasi-Honda (1940 *e*) was discovered by Okabayasi at Kurasiki Observatory on September 30, and independently by Honda at Seto, Hirosimaken, on October 4. It had a nucleus and its magnitude was 11 at the time of discovery. Identity with Comet 1926 i was suggested.

Comet Whipple (1940 *d*) was discovered independently by Paraskevopoulos at Bloemfontein on October 8, and has been given the name Whipple-Paraskevopoulos.

Comet de Kock (1941 *a*) was known in America as Comet Paraskevopoulos (1941 *c*), but was actually discovered first by de Kock at Paarl in South Africa on January 15, when its magnitude was about 6. It was increasing rapidly in brightness, and finally attained magnitude 2.

Comet Friend-Reese was discovered independently by C. L. Friend, Escondido, California, and E. J. Reese, Uniontown, California, on 1941 January 17, its magnitude at the time of discovery being 10. It was diffuse with a nucleus and a tail less than 1° in length.

Comet Encke was discovered by van Biesbroeck on 1941 January 19. Its magnitude was 17 and it was described as diffuse with a nucleus. The late Dr. A. C. D. Crommelin gave the elements and an ephemeris for this comet in *The Handbook of the British Astronomical Association*, 1941. He used the cycle of 59½ years, which reproduces the Jupiter and Saturn perturbations very closely, and although he did not claim anything more than an approximation for the ephemeris, the difference in R.A. (O − C) was only -7^s, the observed and computed declinations practically agreeing.

Comet van Gent was discovered on May 27 by van Gent, Union Observatory, Johannesburg. It was diffuse with central condensation, and its tail was less than 1° in length. This comet was kept under observation for some time by W. Hay at Hendon, and an orbit was computed from his observations.

Comet du Toit-Neujmin was discovered on July 18 by du Toit at Bloemfontein and independently by Neujmin at Simeis. Its magnitude was 10 at the time of discovery. This comet has its aphelion near the orbit of Jupiter, the minimum distance from Jupiter being about one-third of an astronomical unit.

Comet Neujmin-Schwassmann-Wachmann (1) 1925 ii was discovered by Neujmin on August 29. It was diffuse with a nucleus, magnitude 13. An orbit and an ephemeris were computed by J. T. Foxell and K. Pollock (see *The Handbook of the British Astronomical Association*, 1941), but the date of perihelion must have been about 70 days earlier than that assumed.

Comet Schwassmann-Wachmann (2) 1929 i was discovered by Jeffers at Lick

Elements of the Orbits of Comets

Comet	T(U.T.)	ω	Ω	i
		° ′ ″	° ′ ″	° ′ ″
Cunningham	1941 Jan. 16·23136	199 34 51	295 44 58	49 52 21
Okabayasi-Honda	1940 Aug. 15·8440	329 50 16	127 15 15	133 07 30
Whipple-Paraskevopoulos	1940 Oct. 7·8810	235 16	134 10	55 11
De Kock	1941 Jan. 27·66038	268 40 26·0	42 15 07·3	168 11 47·3
Friend-Reese	1941 Jan. 20·38393	132 44 36·6	328 57 24·8	26 16 31·8
Encke	1941 Apr. 18·15	185 11 48	334 36 42	12 19 18
Van Gent	1941 Sept. 3·19730	85 20 50·8	256 43 48·8	94 30 01·6
Du Toit-Neujmin	1941 July 21·18766	69 10 33·3	229 37 07·2	3 14 49·4
Schwassmann-Wachmann (1)	1941 June 23	0 23 10	322 59 43	9 25 56
Schwassmann-Wachmann (2)	1941 Feb. 14·2903	358 01 07	126 02 47	3 43 31

Observatory on September 20. Its magnitude was 17. In *The Handbook of the British Astronomical Association*, 1941, an orbit and ephemeris are given by Messrs. W. P. Henderson and H. Whichello, and the comet was found very close to its predicted place. The date of perihelion passage is 0·035 day earlier than the assumed date.

M. DAVIDSON

SOLAR ACTIVITY

Sunspots.—Sunspot activity during 1941, though far from being inconsiderable, continues a general decline towards sunspot minimum, which may be expected about 1944–45. The provisional sunspot number for the year, based on Greenwich data alone, is 46, as compared with 66 in 1940, and 114 and 110 for the two peak years 1937–38 respectively. The period of greatest sunspot frequency during 1941 was from June to September, the sunspot number for June rising to 67.

During 1941 about a dozen spot-groups reached or exceeded 500 millionths of the Sun's hemisphere. Three of these exceeded 1000 millionths, one just reaching 2000 millionths. Their dates of central meridian passage, latitudes and approximate maximum areas are as follows:—

July 27·1	3° S	1400 millionths.
September 16·9	11° N	2000 ,,
October 29·6	13° N	1100 ,,

No unusual magnetic disturbance occurred near in time to the central meridian passage of the first group. A "great" magnetic storm was, however, associated with the second (*The Observatory*, **64**, 161, 1941). The giant stream itself is briefly described and illustrated in *Journal B.A.A.*, **52**, 34, 1941. With respect to the third group, a small magnetic storm occurred nearly two days after its central meridian passage. There were two other "great" storms during 1941, on March 1–2 and July 4–5 respectively. These two, like the great storm in September, began in each case about one day after a very bright chromospheric eruption (*The Observatory*, **64**, 82, 1941, *P.A.S.P.*, **53**, 257, 1941), but the related spots were not conspicuously big, as was the September group.

The total number of magnetic storms recorded at Abinger during 1941 was sixteen, including the above three "great" storms.

H. W. NEWTON

Observed during 1940 *and* 1941

Comet	q	Period (years)	Equinox	Computers	Reference
(Cunningham)	0·36804	...	1940·0	1, 3	*H.C.O. Card* 557
1940 *e*	1·06372	...	1940·0	2, 4	*H.C.O. Card* 571
1940 *d*	1·0876	...	1940·0	5, 6	*H.C.O. Card* 539
1941 *a*	0·790012	...	1941·0	7	*H.C.O. Card* 579
(Friend-Reese)	0·941885	372	1941·0	5	*H.C.O. Card* 580
(Encke)	0·342157	3·30562	1941·0	8	*Handbook, B.A.A.*, 1941
(Van Gent)	0·874622	...	1941·0	9, 10	*J.B.A.A.*, **52**, 1
(Du Toit-Neujmin)	1·303202	5·44560	1941·0	6	*H.C.O. Card* 604
1925 ii	5·514230	16·29875	1950·0	11, 12	*Handbook, B.A.A.*, 1941
1929 i	2·143875	6·51319	1950·0	13, 14	*Handbook, B.A.A.*, 1941

Computers: 1, Miss M. H. Quirk; 2, Miss E. L. Scott; 3, Hoffman; 4, Panofsky; 5, Maxwell; 6, Grosch; 7, Bobone; 8, Crommelin; 9, Sumner; 10, Davidson; 11, Foxell; 12, Pollock; 13, Henderson; 14, Whichello.

Two of the comets in the list have hyperbolic orbits. The eccentricity of 1940 *e* is 1·00345 and of van Gent 1·000968. A later orbit of the latter comet, computed by 9 and 10, using longer intervals, showed that *e* was 1·002815.

DOUBLE STARS

New Pairs.—Luyten (*Publ. Ast. Obs. Univ. Minnesota*, vol. **3**, No. 3) publishes a Catalogue of 832 double stars with common proper motion in the southern hemisphere.

O. C. Wilson (*P.A.S.P.*, **52**, 404) mentions a Wolf-Rayet visual binary, and Sanford (*P.A.S.P.*, **52**, 408), three new double stars with N-type primaries.

Reuyl (*P.A.S.P.*, **53**, 119) reports the duplicity of the proper motion star Ross 52.

Measures.—Hertzsprung gives the results of measures made on plates taken with the Lick 36-inch refractor (*B.A.N.*, **9**, 113).

R. H. Wilson, jun. (*Publ. Flower Obs.*, vol. 4, part 4), gives interferometer measures, and Phillips (*M.N.*, **101**, 48) has continued his micrometer measures with the 8-inch refractor.

Orbits.—Strand (*P.A.S.P.*, **53**, 247) discusses the orbital motion of the triple system ζ Aqr (ADS 15971).

Berman (*P.A.S.P.*, **53**, 22) gives the spectrographic orbit of the visual binary ζ Her.

Miscellaneous.—Van de Kamp and Burger (*A.J.*, **49**, 65) give the relative proper motion of the multiple system τ Cyg, and van de Kamp and de Vilbiss (*A.J.*, **49**, 66) that of σ Cr B.

Leonard (*P.A.S.P.*, **52**, 400) identifies ADS 13167.

Plaut publishes a note on four southern double stars with large proper motion (*B.A.N.*, **9**, 36) and an additional list of double stars with a variable component (*B.A.N.*, **9**, 49).

Hargreaves writes on the measurement of double stars (*J.B.A.A.*, **51**, 130), and Henroteau describes a new method for the photographic observation of double stars (*J.R.A.S. Can.*, **34**, 456).

W. H. VAN DEN BOS

ADDRESS

Delivered by the President, Professor S. Chapman, on The Source of the Sun's Energy

1. *Kelvin's Discussion.*—The primitive mind may regard the Sun as shining like Moses' bush* : "Behold, the bush burned with fire, and the bush was not consumed." But the nineteenth-century physicist probed more deeply. Kelvin in 1854 discussed the Sun's heat; he saw that the Sun could not be like a coal fire, needing air in order to burn, because the rising products of combustion would quickly cut off the air supply and choke the fire. If like gunpowder the Sun contains all the elements of combustion, it might be a burning fire; but Kelvin could not conceive any substance with enough calorific value † to supply the Sun's heat for more than a few thousand years. He saw also that the heat could not reach the surface from the interior by conduction, which is far too slow; but it might be carried by convection, as in the Earth's atmosphere. He did not think the Sun was shining merely by virtue of original heat, as he could not imagine any substance capable of storing enough heat for the emission which has continued (said he) "without sensible, if any, abatement for 6000 years." He concluded that the energy must be supplied by meteors falling continually into the Sun, and imparting to it, in the form of heat, the kinetic energy acquired under the Sun's attraction.

2. *Kelvin's Second Discussion.*—In 1862 Kelvin reconsidered the question, and abandoned the meteor theory of the Sun's heat, because there could not be enough meteoric matter near the Sun to supply the necessary energy without too greatly affecting cometary orbits in this region. Instead, he adopted the view proposed by Helmholtz, that the Sun's heat is continually being renewed at the expense of its gravitational energy, as it shrinks under its own self-attraction. He calculated that this process could account for 20 million years' supply of heat, but that mankind cannot "continue to enjoy the light and heat essential to their life for many millions of years longer, unless sources now unknown to us are prepared in the great storehouse of creation."

Thus Kelvin, at the age of thirty-eight, was more ready than at thirty to think in millions than in thousands of years, and to add a saving clause to his conclusions. But he left the impression with the scientific public that the creation of the world could not be more than 20 million years ago. Geologists, in particular, considered this inadequate for the slow formation of the terrestrial strata and the evolution of the organic life revealed in them by the fossils. Half a century later the study of the radioactive elements in the Earth's crust showed that this must have been formed about 2000 million years ago; hence the age of the Earth, and of the Sun, cannot be less than this.

The great storehouse of creation must indeed contain sources of energy beyond Kelvin's imagination. Their nature has been clearly revealed ‡ only during the past decade, through progress in chemical and physical knowledge.

While astronomers have been exploring ever more distant regions of the universe, physicists have been probing the almost infinitely little. From these diverse highlands of discovery new streams of thought have flowed to merge in the mighty river of astronomical knowledge, a synthesis of incomparable grandeur.

Let us therefore for a time forget the telescope and the observatory, and consider the nature of matter as revealed by chemistry and physics.

3. *The Periodic Table.*—Astronomy was already a venerable science when chemists

* Exodus, iii, 2.

† Heat or energy produced per lb. or per gram.

‡ There still remain difficulties as to the source of the energy of the brightest stars; see R. d'E. Atkinson, *Ap. J.*, **84**, 83, 1936; also *M.N.*, **100**, 500, 1940.

turned from attempts to transmute base metals into gold, and began patiently to study the chemical properties of matter from pure scientific curiosity. Dalton, finding that gases combine in definite (and multiple) proportions, revived the atomic theory of Democritus. Chemists isolated many of the elements, and gradually examined an immense array of their compounds. In 1869 Mendelejeff gave structure and order to a great body of chemical knowledge by his periodic table of the elements. This table, at first incomplete, has since been filled in and enlarged, and now constitutes the ground plan of chemistry. It arranges the 92 chemical elements so as to show their associations and the progression of their chemical properties. The "place" number of the element in this table, starting with 1 for the lightest element, hydrogen, and ending with 92 for the heaviest known element, uranium, is called the *atomic number* (Z).

4. *Isotopes.*—Chemists formerly thought that all atoms of the same element were alike, but their colleagues the physicists have shown that they can differ in mass; such differing atoms of the same element are called *isotopes*, because their chemical properties give them the *same place* in the periodic table. The periodic table may therefore be supplemented by a list giving, for each element, the masses of its various isotopic species of atom; the list may also give the relative abundances of the different isotopes—that is, the percentage numbers of each; these are usually the same, within narrow limits, whatever the (terrestrial) source of the matter containing the element.

5. *Atomic Masses.*—The unit (u_m)* in which physicists usually express the *mass* of an atom is one-sixteenth of the mass of the most abundant type of oxygen atom.

A mass so expressed may be called the *mass-number* A of the atom; for the said oxygen atom $A = 16$, by definition. For all atoms the mass-numbers are nearly integers (or whole numbers); often A is quoted only to the nearest integer A', which may be called the *mass-integer*. Table I gives the mass-integers for the isotopes † of the eight lightest elements, and their relative abundances; Table III gives the actual value of A (with an indication of the probable error).

TABLE I *

Z	Symbol	Element	A'	Per cent.
1	*H*	Hydrogen	1	99·98
			2	0·02
2	*He*	Helium	3	0·00001
			4	99·99999
3	*Li*	Lithium	6	7·9
			7	92·1
4	*Be*	Beryllium	9	100
5	*B*	Boron	10	18·4
			11	81·6
6	*C*	Carbon	12	98·9
			13	1·1
7	*N*	Nitrogen	14	99·62
			15	0·38
8	*O*	Oxygen	16	99·76
			17	0·04
			18	0·20

*[1] Extracted from a much more extensive table by J. J. Livingood and G. T. Seaborg, *Rev. Mod. Phys.*, 12, 30, 1940.

Chemists, working with the mixtures of isotopes in which the elements occur in Nature, measure the average atomic mass, which they call the atomic weight; when the

* In grams $u_m = 1{\cdot}660 \times 10^{-24}$; for this and other physical constants quoted in this Address, see R. T. Birge, *Rev. Mod. Phys.*, 13, 233, 1941, and *Rep. Prog. Phys.*, 8, 90, 1942.

† See also §§ 18, 23.

abundances of different isotopes are not too unequal, these "average" atomic weights may differ appreciably from an integer (*e.g.* boron; *cf.* Table I).

6. *Atomic Structure.*—In Kelvin's youth, atoms were often pictured as tiny hard balls, though it was realized that their characteristic and often complicated spectra showed this view to be inadequate. We now know that a normal atom of place-number Z consists of a tiny nucleus (of radius 10^{-12} or 10^{-13} cm.) surrounded by an ordered establishment of Z electrons. Each electron carries a definite electric charge, of the sign which by convention is called negative; its magnitude provides the natural unit (u_e) * of electric charge. As the normal atom is electrically neutral, the nucleus must carry a positive charge of Z such units. Thus the place-number Z is also the *charge-number* of the nucleus.

The atom can lose one or more electrons, or even have one too many; it then carries a resultant charge, positive in the first case, negative in the second, and is called an atomic ion (positive or negative). But its resultant charge tends to attract additional electrons, or to repel the surplus electron, so as to restore the normal number Z, which is thus the main governing factor in the atomic structure. The chemical relations of atoms are merely their external relations with other atoms, and these are determined by their outer electronic structures; hence Z determines the chemical properties of the element, and therefore its place in the periodic table.

Thus a hydrogen atom has 1 electron, a helium atom has 2, and their nuclear charges are $+1$ and $+2$.

The *mass* of an electron, in atomic units (u_m, § 5), is very small, only 0·000548; to make up one atomic unit of mass, 1822 electrons are needed. Even in uranium, with 92 electrons, their total contribution to the atomic mass A is only 0·05 unit. Hence in all cases practically the whole mass A of an atom is concentrated in the nucleus.

7. *Chemical and Nuclear Symbols.*—The chemical symbol of an element ordinarily denotes an atom † of the element, *e.g. He* denotes an atom of helium. To distinguish between atoms of the same element but of different mass, the mass-integer may be added as an affix: *e.g.* H^1 or H^2 for hydrogen.

The atomic symbol and affix may also be used for the atomic nucleus, but to distinguish symbols for nuclei one may add their charge numbers Z, as a left-hand suffix, *e.g.* ${}_1H^1$ or ${}_1H^2$ for hydrogen nuclei, ${}_2He^3$, ${}_2He^4$ for helium nuclei; the value of Z (unlike that of A) is determined by the chemical symbol (and *vice versa*), and can be seen from the periodic table.

The symbol e may be used for an electron; to indicate its mass-integer (0) and charge (-1) it may be written ${}_{-1}e^0$.

Special names are given, as follows, to the nuclei ${}_1H^1$ (a proton), ${}_1H^2$ (a deuteron) and ${}_2He^4$ (an alpha—or α-particle).

8. *The Neutron.*—In 1932 a new kind of particle, called a neutron ‡, was discovered, almost equal in mass to the proton ${}_1H^1$, but with no charge ($Z=0$); its symbol is ${}_0n^1$.

Chemists long thought that all the different kinds of atom may be built up from the same unit, which was naturally taken to be the lightest atom, that of hydrogen. When the nuclear and electronic structure of the atom was discovered, this speculation was applied to nuclei rather than to the whole atom, and the proton ${}_1H^1$ was taken to be the building unit. But a nucleus of mass A cannot consist simply of A protons, because its charge Z would then equal A, whereas always (except for the proton itself) A exceeds

* In c.g.s. electrostatic units $u_e = 4{\cdot}802 \times 10^{-10}$.

† Or a gram atom—that is to say, A grams, where A is the mass-number.

‡ The neutron is believed to be unstable, and to disintegrate into a proton, with the emission of an electron, in a few hours (if the neutron remains free); see H. A. Bethe, *Rev. Mod. Phys.*, **8**, 201, 1936. But ordinarily neutrons collide with and are captured by atomic nuclei before they have time to disintegrate; the rate at which they are thus captured naturally depends on the density of matter present. Protons (H^1 nuclei) capture neutrons particularly easily; see J. H. Manley, L. J. Haworth and E. A. Luebke, *Phys. Rev.*, **61**, 152, 1942.

Z; indeed, for all but the few lightest elements, A equals or somewhat exceeds $2Z$. Before 1932 it was supposed that $A - Z$ electrons in the nucleus neutralized the excess charge; *e.g.* that the lithium nucleus ${}_3Li^7$ contained 7 protons and 4 electrons, and the helium nucleus ${}_2He^4$, 4 protons and 2 electrons (fig. 1). Nowadays it is thought that nuclei are made up of A protons and neutrons, namely, Z protons and $A - Z$ neutrons.

9. *The Positive Electron.*—Yet another important discovery * of the year 1932 was a new type of *electron*, of the same mass as the long-known negative electron, but with

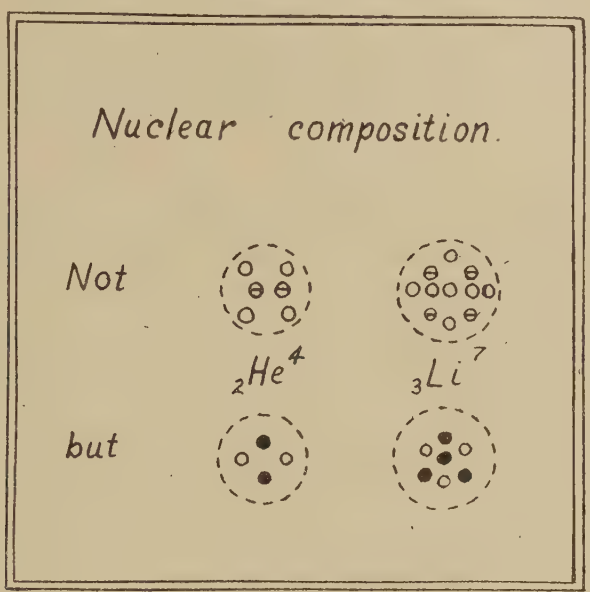

FIG. 1.—*Nuclear structure (diagrammatic): The earlier conception (above), involving protons (represented by a simple circle) and negative electrons (represented by a circle with a minus sign within it), and the present-day conception, involving protons and neutrons (represented by black circles). The greater simplicity of the later conception is evident, and would be still more apparent for heavier nuclei.*

a positive charge; its symbol is therefore ${}_1e^0$. (Alternatively the two types of electron are indicated by the symbols e^- and e^+, or β^- and β^+.)

The discovery of the positive electron (or *positron*) was delayed because of its normally very short life. If a positive and a negative electron meet together they can "annihilate" one another † and be transformed into two packets or *photons* of radiation. In terrestrial conditions this probably happens in about a millionth of a second.

10. *Molecules and Chemical Reactions.*—The chemical reactions so extensively studied by chemists are concerned with the formation and transformation of *molecules*, each consisting of one or more atoms, of the same or different elements; the molecule is the smallest portion of matter that has the chemical properties of a compound, and the atom is the smallest portion of an element that can combine with others to form molecules. Such chemical combinations involve linkages only of the outer electronic structures of

* Since then a further elementary particle (the *meson* or *mesotron*) has been discovered; the interconnections between the various elementary particles are still obscure, and the speculations relating to them often include reference to another (as yet hypothetical) particle called the *neutrino*; see H. A. Bethe, *Rev. Mod. Phys.*, **8**, 186, 1937. There may be more than one kind of meson, with charges of different sign, or no charge; the mass is intermediate between that of an electron and a proton.

† See R. Beringer and C. R. Montgomery, *Phys. Rev.*, **61**, 222, 1942, and earlier references there cited.

the atoms; the atomic nuclei remain distinct. Thus an atom has one nucleus, and a molecule has more than one.

11. *Chemical Equations.*—Ordinary chemical reactions are symbolized by equations such as

$$(1)\ 2C + O_2 \rightarrow 2CO, \qquad (2)\ 2CO + O_2 \rightarrow 2CO_2,$$

where the non-suffix integers 2 indicate two independent atoms (C) or molecules (CO or CO_2).

These equations represent successive stages in the combination (or combustion) of carbon; in (1), two carbon atoms combine with one molecule of oxygen (O_2) to form two carbon monoxide molecules (CO); in (2), such a pair of CO molecules combine with a further oxygen molecule to form two molecules of carbon dioxide (CO_2). Here the only suffixes are to the *right* of the chemical symbols; they indicate the number of *atoms* in the *molecule.*

In such "ordinary" chemical reactions the elements retain their identity. The molecular grouping of the atoms is changed, but the number of atoms of each element is not altered. This can easily be checked in (1) and (2); there are two C atoms on each side of (1), and also of (2); two oxygen atoms occur on each side of (1), and four on each side of (2).

12. *Radioactive Transformations.*—Such reactions are entirely different from the more fundamental change—the transformation of an atom into the atom of a different element—which the alchemists sought to produce. The nineteenth-century chemists, who had turned from this attempt, and prospered greatly thereby, came to deride the possibility of transmutation. But the discovery of radium and the other radioactive elements showed that the process was actually occurring spontaneously in Nature. A change from one element to another means a change in Z, the charge of the nucleus, and thus affects the very citadel of the atom; the outer structure is easily adjusted to a change in the nucleus; if Z is decreased, the surplus electrons are repelled away, or if Z is increased, additional electrons are attracted.

13. *Disintegration : α-, β- and γ-Rays.*—The natural radioactive substances undergo a succession of chemical changes, in each of which a charged particle is expelled with great energy by the nucleus. These particles or "rays" are of two kinds, namely, α-particles ($_2He^4$) and electrons * ($_{-1}e^0$, also called β-particles). After the emission of an α-particle the nuclear charge Z is reduced by 2, and its mass by 4. The emission of an electron or β-ray *increases* Z by 1, and leaves the mass (almost) unaltered.

Throughout these natural radioactive transformations the nucleus steadily decreases in mass, mainly by loss of α-particles. The process ends with a lead nucleus. At several stages in the decay, intense *radiation* (called γ-rays, or gamma radiation), of very short wave-length, is emitted.

14. *Nuclear Equations.*—Two such transformations are symbolized by the *nuclear* equations.†

$$(1)\ {}_{88}Ra^{226} \rightarrow {}_{86}Rn^{222} + {}_2He^4, \qquad (\alpha\text{-ray})$$

$$(2)\ {}_{82}Ra_B{}^{214} \rightarrow {}_{83}Ra_C{}^{214} + {}_{-1}e^0 + \gamma, \qquad (\beta\text{- and } \gamma\text{-rays})$$

which refer to the first and fourth stages in the disintegration of radium (Ra).‡ In such

* The electrons are not supposed to exist inside the nuclei, any more than a quantum of light emitted by a hydrogen atom, when its outer electron moves from one energy level to another, is supposed to exist in (the outer structure of) the hydrogen atom before the emission occurs; see H. A. Bethe, *Rev. Mod. Phys.*, **8**, 184, 1937.

† In (2) the symbol γ indicates that γ radiation is emitted.

‡ *Rn* is the symbol for radon (formerly known as radium emanation, with the symbol *Em*); Ra_B and Ra_C are symbols used for two successive descendants of the radium nucleus; reference to the periodic table, for $Z = 82$ and $Z = 83$, shows that they are chemically identical with lead and bismuth.

"equations" the sum of the suffixes is the same on the two sides, and so also is the sum of the affixes, corresponding to the conservation of the total charge and (very approximately) of the total mass (§§ 5, 7).

15. *Half-lives of Unstable Nuclei.*—Radioactivity indicates instability within the nucleus, but the break-up is not immediate. In any given number of unstable nuclei of one kind, a definite proportion, depending on the kind, will break up in unit time. The time taken for the disintegration of half of them is called their half-life. These half-lives have an extremely wide range of values * for different elements in the radioactive series, *e.g.* from $1{\cdot}8 \times 10^{10}$ years for ${}_{90}Th^{232}$, $4{\cdot}4 \times 10^{9}$ years for ${}_{92}U^{238}$, down to 10^{-6} seconds for ${}_{84}Po^{214}$, and even less (possibly only 10^{-9} seconds) for ${}_{84}Po^{212}$.

Uranium and thorium have exceptionally long half-lives, so that much still remains of what was present in the Earth when its independent existence began; their continued slow decay maintains a supply of all their long chain of successive disintegration products.

The emission of α-particles at several stages during this natural disintegration suggests that such particles are exceptionally stable structures, which retain their identity as compound units within larger nuclei.

16. *Alpha Particles as Research Tools.*—Rutherford, besides taking a great part in elucidating these natural radioactive processes, used the α-particles as tools of further research. His discovery of the existence of the *nuclei* of atoms was made by showing that fast α-particles, while passing through matter, are sometimes so greatly deflected as to imply a very close encounter, within 10^{-12} or 10^{-13} cm., with a particle of similar mass. Later, in 1919, he became the founder of a true alchemy, by using α-particles to transmute chemical elements artificially.

17. *Man-produced Nuclear Reactions.*—Rutherford's first success was to transform a nitrogen nucleus (${}_{7}N^{14}$) together with an α-particle (${}_{2}He^{4}$) into an oxygen nucleus (of the rare type ${}_{8}O^{17}$, *cf.* Table I) together with a proton. This reaction is indicated by the equation

$$ {}_{7}N^{14} + {}_{2}He^{4} \rightarrow {}_{8}O^{17} + {}_{1}H^{1}, $$

in which (*cf.* § 14), on the two sides, the sums of the suffixes are the same, and also the sums of the affixes.

A close encounter was necessary for the reaction, so that the α-particle had to be projected towards the nitrogen at high speed, because nuclei repel one another strongly, on account of their electric charges (of like sign). Rutherford succeeded in transforming chemical elements because he had found, in Nature, means adequate to the task; the old alchemists failed because their appliances were feeble and utterly insufficient.

Thus began a new "nuclear chemistry," whose intense interest and importance stimulated the efforts of physicists and chemists in all parts of the world.

Rutherford and his followers were not long content to use only the α-particle projectiles provided by Nature; they devised means of accelerating protons and deuterons (§ 7) to high speeds; they also used neutrons, which, whether fast or slow, can approach closely to nuclei without being repelled, because they have no electric charge. Gamma rays were also found capable of disrupting nuclei, "shaking" them apart by rapid alternations in the electric field.

In the course of the last ten or fifteen years an enormous number of nuclear reactions and transformations have thus been produced.

18. *Man-produced Radioactive Nuclei.*—In the course of such studies it was found that many types of nuclei were produced that had never previously been observed, because normally they do not occur in terrestrial matter; they are unstable and short-lived, changing spontaneously into a nucleus of different charge Z. Unstable nuclei have now been produced for every value of Z (up to the natural heavy radioactive elements); in other words, every element is known to have one or more radioactive isotopes.

* See "Radioactive constants as of 1930," *Rev. Mod. Phys.*, 3, 427, 1931.

The "artificial" radioactive nuclei emit positive or negative electrons, not α-particles (except that ${}_3Li^8$, after emitting a negative electron, splits up into two α-particles). Exceptionally, a nucleus may capture one of the electrons in the outer atomic structure, namely, one of the nearest (or K) electrons, as in the case of ${}_4Be^7$.

TABLE II *

Z		Half-life	
1	${}_1H^3$	31 ± 8 yrs.	$\rightarrow {}_2He^3 + {}_{-1}e^0$
2	${}_2He^6$	0·8 sec.	${}_3Li^6 + {}_{-1}e^0$
3	${}_3Li^8$	0·9 sec.	${}_2{}_2He^4 + {}_{-1}e^0$
4	${}_4Be^7$	43 days	$+ {}_{-1}e^0 \rightarrow {}_3Li^7 + \gamma$
5	${}_5B^{12}$	0·02 sec.	$\rightarrow {}_6C^{12} + {}_{-1}e^0$
6	${}_6C^{10}$	8·8 sec.	${}_5B^{10} + {}_1e^0$
,,	${}_6C^{11}$	21 min.	${}_5B^{11} + {}_1e^0$
7	${}_7N^{13}$	9·9 min.	${}_6C^{13} + {}_1e^0 + \gamma$
,,	${}_7N^{16}$	8 sec.	${}_8O^{16} + {}_{-1}e^0$
8	${}_8O^{15}$	126 sec.	${}_7N^{15} + {}_1e^0$

* From the same source as Table I, except that the half-life there given for H^3 (150 days) is replaced by the later estimate due to R. D. O'Neal and M. Goldhaber, *Phys. Rev.*, 58, 574, 1940. See also the footnote to Table III.

The radioactive isotopes for the eight lightest elements are shown in Table II, and their modes of spontaneous disintegration; γ indicates the emission of γ radiation. The half-lives are also given.

19. *Energy Transformations and Units.*—We consider next the *energy* aspects of ordinary and nuclear chemistry.

Kelvin well knew that different forms of energy are interconvertible, in fixed ratios; he calculated, for example, that the kinetic energy of the planetary motions within the solar system, once regarded as the grandest phenomena of mechanical energy in Nature, equals only about twenty years' outpouring of solar energy.

The c.g.s. unit of mechanical energy is the erg, equal to the kinetic energy ($\frac{1}{2}mv^2$) of 2 grams ($m=2$) moving with a speed of 1 cm. per second ($v=1$). The c.g.s. unit of heat energy is the calorie, the amount needed to raise the temperature of 1 gram of water (at 15° C.) by 1° C. Both these units are too small for the engineer, but the erg is much the smaller (1 calorie = 41·8 million ergs). The electrical engineer's unit of power (rate of energy supply) is the kilowatt ($=10^{10}$ ergs/sec.); his unit of energy (for which the consumer pays a penny or so) is the kilowatt-hour ($=3{\cdot}6 \times 10^{13}$ ergs, or nearly a million calories—sufficient to raise the temperature of 8·6 litres or 1·9 gallons of ice-cold water to boiling-point).

20. *The Sun's Energy Output.*—In all such units the Sun's energy output is very large. In kilowatts it is $3{\cdot}78 \times 10^{23}$, or nearly half a million million million million. Expressed as so much per square centimetre of *surface*, however, it seems quite moderate, 6 kilowatts or 8 horse-power. Even the erg is an appropriate unit for the Sun's energy output per unit *mass*, namely, 1·9 ergs per gram per second. But we jump again to high figures when we calculate the total output in ergs per gram, during the estimated minimum life of the Sun—2000 million years or $6{\cdot}3 \times 10^{16}$ seconds—namely, $1{\cdot}2 \times 10^{17}$ ergs per gram or 3310 electrical units per gram; per lb. of solar matter the amount is 454 times greater (1·5 million electrical units). Less than 1 per cent. of this can be supplied by the gravitational energy of contraction: hence the average calorific value of solar matter would appear to be at least 1·5 million electrical units per lb., a figure which we may compare with $4\frac{1}{4}$, the corresponding calorific value of coal.* Hence, as Kelvin concluded, ordinary chemical transformations, affecting only the linkages between the light outer structures of the atoms (§ 6), cannot provide the Sun's energy output.

* Or $1\frac{1}{6}$ units per lb. if we include in our reckoning also the necessary oxygen. For other substances the calorific value per lb. (thus reckoned) is smaller, or of similar magnitude.

21. *Energy of Linkages within Nuclei.*—The discovery and elucidation of radioactivity, however, revealed the presence of far greater stores of energy in certain kinds of matter. This energy is located in the nuclei, not in the outer structure of the atoms; it is energy of linkage between the constituent particles of nuclei (protons and neutrons, § 8). It is so great that uranium and its disintegration products, in their equilibrium proportions, pour out energy at the rate of about 1 erg per gram per second, or half the average output of solar matter (§ 20). This does not even half solve the problem of the energy output of the Sun, which contains only a small proportion of uranium and its products, but it does suggest where the "great storehouse of creation" (§ 2) is to be sought.

22. *Mass and Energy.*—The nineteenth-century doctrine of equivalence between different forms of *energy* was extended by Einstein (1905) to include *mass*; mass itself is a measure of energy. The equivalence may be expressed in the form

$$m \text{ grams} = mc^2 \text{ ergs} \quad \text{or} \quad E \text{ ergs} = E/c^2 \text{ grams},$$

where $c = 3 \times 10^{10}$ (more exactly, $2{\cdot}9978 \times 10^{10}$), which is the velocity of light *in vacuo*, in cm. per sec.

The Sun's energy output is so great (§ 20) that its consequent loss of mass is large in human reckoning, namely, 4 million tons per second; but the Sun's mass is so great that this loss, continued for 2000 million years, would reduce the mass only by 1 part in 7500.

Einstein's relation does not indicate the *nature* of the energy, whose presence may not be apparent to us in familiar forms: just as it is not evident to our senses that ordinary heat energy is merely mechanical energy of the atomic and molecular motions.

The mass/energy ratio of equivalence is so extreme that any ordinary change in the kinetic or thermal or chemical energy of a body has no measurable effect upon its mass.

The mass m' of a moving particle exceeds its mass m at rest (or its *rest mass*) by E/c^2, where E is the kinetic energy ($=\frac{1}{2}mv^2$ approximately, or more exactly $mc^2/\sqrt{(1-v^2/c^2)} - mc^2$); but this increase is appreciable only when v approaches c, the velocity of light. As regards heat energy, the combustion of 12 grams of coal with 32 grams of oxygen (§ 11) liberates 95,000 calories; this is equivalent to only 10^{-10} of the combined mass of the carbon and oxygen. The CO_2 produced is lighter than the original carbon and oxygen by this fraction of 44 grams—a change beyond the measuring capacity of the finest chemical balance; hence the chemist rightly regards his substances as unchanged in mass by their reactions. But in *nuclear* changes, whether natural disintegrations or those produced in laboratory experiments, the energy changes are so much greater that the change of mass is not immeasurably small.

23. *Accurate Atomic Masses.*—The energy-mass equivalence, and the study of nuclear changes involving great energy per gram, made it important to determine the masses of all varieties of atom with the utmost accuracy. Physicists, using powerful new instruments such as the mass-spectrograph, have collaborated with chemists in this work. Einstein's equation (§ 22) has been confirmed by the measurement of the masses and energy changes in nuclear reactions, and now the equation is applied to other reactions, in which the energy changes are measured, to determine or to check the masses of other atoms.*

For the eight lightest elements (*cf.* Table I) the atomic masses (§ 5), which refer to

* In such experiments beams of fast-charged particles are used (*e.g.* protons), and as these are raised to high speed by passing through strong electric fields, physicists often indicate the kinetic energy of their particles by the potential difference which will impart this kinetic energy to a particle carrying one electronic charge (§ 6). This potential difference may be expressed either in (electron-) volts (ev.), kilovolts (1 kev. = 1000 ev.) or megavolts (1 mev. = 10^6 ev.); one volt potential difference is 1/300 c.g.s. electrostatic unit, so that the energy of 1 electron-volt is $u_e/300$ or $1{\cdot}602 \times 10^{-12}$ erg. The corresponding mass is $1{\cdot}602 \times 10^{-12}/c^2$ or $1{\cdot}782 \times 10^{-33}$ gram, or $1{\cdot}073 \times 10^{-9}$ atomic units of mass (u_m, § 5); hence 10^{-5} of such an atomic unit is equal to 9·32 kev.

the atoms when at rest (with their full complement of Z electrons), are indicated in Table III by giving $10^5(A - A')$, where A' denotes the mass-*integer* (§ 5), whose value is shown in the atomic symbol; thus, for H^1, $A = 1.00813$, and $A' = 1$, so that $10^5(A - A') = 813$. The estimated uncertainty of $10^5(A - A')$ is indicated in the "Error" column.

TABLE III †; $10^5(A - A')$

e^0	55	± 0	Be^7	1909*	±7			
n^1	894*	3				N^{13}	994*	± 6
H^1	813	0	Be^9	1496	6	N^{14}	752	2
H^2	1473	1				N^{15}	494	8
H^3	1702*	2	B^{10}	1617	7	N^{16}	645*	?
He^3	1703	1	B^{11}	1290	5	O^{15}	780*	?
He^4	386	3	B^{12}	1680*	?	O^{16}	(standard)	
He^6	2090*	?	C^{10}	2086*	?	O^{17}	450	6
Li^6	1692	5	C^{11}	1505*	7	O^{18}	492	18
Li^7	1816	6	C^{12}	388	2			
Li^8	2497*	7	C^{13}	756	4			

* Radioactive (see Table II).

† From a table by S. Flügge and J. Mattauch, *Phys. Zs.*, **42**, 1, 1941, which also includes the masses of radioactive atoms He^5, Be^8, Be^{10}, B^9, C^{14}, omitted here and in Table II because I have not found any published determinations of their half-lives. I have also omitted O^{19}, given by Livingood and Seaborg, but not by Flügge and Mattauch.

24. *The Proton-Proton Reaction.*—The use of atomic masses in considering the energy relations of a nuclear reaction may be illustrated by considering the simplest of all such reactions, namely, the combination of two protons to form a deuteron:

$$ {}_1H^1 + {}_1H^1 \rightarrow {}_1H^2 + {}_1e^0. \qquad (1) $$

A positive electron is released, which soon combines with a negative electron to dissolve into γ-radiation (here denoted by ${}_0\gamma^0$, to illustrate the conservation of charge and, approximately, of mass):

$$ {}_1e^0 + {}_{-1}e^0 \rightarrow {}_0\gamma^0. \qquad (2) $$

Thus two protons and one negative electron are finally transformed into a deuteron and γ-radiation.

It is convenient, in considering the change of the rest-masses, to add the mass of an electron (§ 5) to both sides of the account. We then have, initially, the masses of two protons and two electrons, equal in all to that of two H^1 atoms,* namely, $2 \times (1.00813)$ or 2.01626 (*cf.* Table III); finally we have the masses of a deuteron and one electron, equal to the mass of one H^2 atom, namely, 2.01473.

Thus 0.00153 atomic unit of rest-mass is missing after the reaction; this is the energy of the γ-ray (less any additional kinetic energy of the H^2 atom or of the particle in whose field (2) occurs). It is a fraction 0.00153/2.016 or 0.00076 of the original mass; hence it corresponds to 0.00076 c^2 or 6.8×10^{17} ergs per gram. This is more than five times the estimated minimum *average* calorific value of solar matter (§ 20).

It is not difficult to see that in any such calculation for a nuclear reaction we can

* More exactly, the sum of the masses of a proton (or deuteron) and an electron slightly exceeds the mass of a normal H^1 (or H^2) atom, because the kinetic energy gained by the electron in taking up its normal place in the H^1 atom, under the attraction of the proton, is liberated as radiation. Conversely, this energy must be supplied in order to separate the electron from the nucleus: the atom is then ionized, and the energy required is called the ionization energy. Physicists usually express ionization energy in terms of electron-volts (§ 23, footnote). The ionization energy for a single H^1 or H^2 atom is 2.12×10^{-11} erg or 13.2 ev. The mass corresponding to this energy is 2.4×10^{-32} gram, or in atomic units (§ 5) 1.5×10^{-8}. Since Table III gives A (by means of 10^5 times $A - A'$) only to the fifth decimal place, it is clear that in (1) we may neglect the ionization energy, which for H^1 or H^2 only affects the eighth decimal place.

always use the masses of the atoms in place of the nuclear masses, if we neglect the ionization energy; also, since the integer parts (A') of A balance on the two sides of the equation, it is only necessary to consider the non-integer parts, $A - A'$.

25. *Energy-absorbing Reactions.*—Not all nuclear reactions liberate energy, as when two protons combine (§ 24). In Rutherford's first nuclear reaction (§ 17), for example, the total rest-mass was *increased* by $10^{-5}(450 + 813 - 752 - 386)$ * or $10^{-5} \times 125$ unit per atom. As the combined mass of the participating nuclei was 18 units, the reduction was by the fraction ·000125/18 or 0·00007, equivalent to 6×10^{16} ergs per gram. The increased mass is gained at the expense of the kinetic energy with which the original α-particle is shot towards the nitrogen nucleus; the resulting oxygen nucleus and proton have 6×10^{16} ergs less kinetic energy per gram.

26. *The Conditions necessary for Nuclear Reaction.*—The energy released per gram in nuclear reactions may exceed the minimum average calorific value of solar matter (§ 24), but such reactions may on the contrary *absorb* energy (§ 25), so that further consideration is needed to determine whether the Sun's energy output is of nuclear origin.

Nuclei react with one another only when they are very close together. Owing to their electric charges (e_1, e_2 in electrostatic units) they repel one another, and if they are to approach to a mutual distance a cm. their initial kinetic energy of relative motion must at least equal e_1e_2/a ergs. In laboratory experiments such kinetic energy is imparted to nuclei by passing a stream of atomic ions (§ 6) through a strong electric field; but in Nature, particles have high speeds only when they form part of hot bodies.† At absolute temperature $T°$ the *average* translatory kinetic energy of each free particle is $\frac{3}{2}kT$, where $k = 1{\cdot}380 \times 10^{-16}$; if two nuclei each having this energy are directly approaching each other, their kinetic energy of relative motion is $3kT$, and if this equals e_1e_2/a, where $e_1 = Z_1u_e$, $e_2 = Z_2u_e$ (§ 6),

$$T = Z_1Z_2u_e^2/3ka = 5{\cdot}5 \times 10^{-4}Z_1Z_2/a.$$

If we take $a = 10^{-11}$ cm. (an over-estimate of the distance at which nuclei are likely to react), this gives $T = 5{\cdot}5 \times 10^7\ Z_1Z_2$, which is greater, the greater the charge-numbers of the nuclei. It is least for two protons ($Z_1 = Z_2 = 1$), namely, 55 million degrees; at this temperature many proton pairs would attain the mutual distance 10^{-11} cm. because the *average* nuclear kinetic energy is sufficient, and the only further condition is that the protons should be moving towards each other; this would often happen. But such approaches would occur often also at somewhat lower temperatures, of a few million degrees, because at any time there are always some particles with energy above the average; the distribution of their speeds and energies is given by Maxwell's celebrated formula.

This calculation, though crude, indicates that only at very high temperatures will nuclear reactions be likely to occur, even between nuclei which have low charge-numbers (and small mass).

27. *Matter at High Temperatures.*—In the Sun and stars such high temperatures exist only in the deep interior; the surface temperatures are reckoned in thousands rather than millions of degrees. The observed outflow of radiation is itself evidence that the temperature decreases outwards, at least from the depth at which the energy is generated. Owing to the weight of the overlying matter, the high temperatures are combined with high pressure.

In hot matter the violence of the continual molecular and atomic impacts is proportional to the average energy of random motion per particle, $\frac{3}{2}kT$; even at the surface of the Sun few molecules can long survive the repeated collisions without breaking up into separate atoms, and many atoms become positive ions (§ 6) by losing one or more

* See $10^5(A - A')$ in Table III for O^{17}, H^1, N^{14}, He^4.

† There are a few exceptions, such as cosmic rays and the fast particles ejected by radioactive elements.

electrons. The greater the depth and the higher the temperature, the more the electrons are torn from each atom. Though such electrons may occasionally reunite with an atomic ion, for most of their time they lead independent lives; each has the same average energy of random motion, and makes the same contribution to the pressure, as any other free particle, whether this be a highly ionized atom or a bare nucleus stripped of all its electrons. Practically all the lighter atoms are reduced to bare nuclei at the depths where the temperature attains some millions of degrees; there only the heavy atoms can retain a few of their electrons, tightly bound by the attraction of the strong nuclear charge.

In ordinary matter the nuclei are shielded from one another by their outer framework of electrons, but in the deep interior of the Sun the lighter nuclei, which have lost this protection, are kept apart only by their mutual repulsion. Those with sufficient kinetic energy, perhaps much exceeding the average value $\frac{3}{2}kT$, will approach closely and react with one another. This will happen much more rarely to the heavier nuclei, whose repulsive field is greater.

28. *Two Special Properties of "Crushed" Matter.*—Incidentally this "crushed matter," as Gamow calls it, in which the atoms have lost all or nearly all their outer electronic framework, is much more compressible than ordinary matter; it retains the properties of a perfect gas at densities far exceeding that of water.

Moreover, the statical equilibrium of such matter, under its own weight, is far less dependent on its chemical composition than in ordinary gases. At a given temperature and in a gravitational field of given intensity, the extension of a column of gas—that is to say, the distance between two levels at which the pressures are in a given ratio—is proportional to the number of free particles per unit mass, or, what is equivalent, inversely proportional to $\bar{A}$, the average mass per particle.

For a gas composed wholly of atoms of one kind (mass-number A, charge number Z), $\bar{A}=A$ when the atoms are in their normal state, but when they are fully ionized, so that each divides into $Z+1$ particles (1 nucleus and Z electrons), it is $A/(Z+1)$; thus for hydrogen (H^1) $\bar{A}=\frac{1}{2}$, for helium (He^4) it is $\frac{4}{3}$, for lithium (Li^7) it is $\frac{7}{4}$, and for still heavier elements it is approximately 2. For a *mixture* of atoms of different chemical elements, $\bar{A}$ may range from 1 to 240 when they are in their normal states, as the composition ranges from pure hydrogen, through mixtures of any or all elements in differing proportions, to pure uranium; but if the same matter is "crushed" (or completely ionized) the extreme range in $\bar{A}$ is only from $\frac{1}{2}$ (pure hydrogen) to 2·6 (pure uranium); if the heaviest atoms are not fully ionized, the upper limit is more nearly 2. Hence, when considering the mechanical equilibrium of a great self-gravitating globe of hot gas like the Sun, it is far less important to know the chemical composition of the gas in the deep interior, if the matter there is in the "crushed" state, than it would be if the atoms had their normal constitution. What chiefly determines $\bar{A}$ is the proportion of hydrogen and (much less important) of helium. Certain evidence (§ 37) suggests that the proportion of hydrogen in the Sun is considerable, of the order 35 per cent. (by mass).

29. *Energy Generation within the Sun.*—We have seen that if nuclear reactions occur in the Sun they are likely to begin at temperatures of some millions of degrees; these will be found (if at all) only at considerable depths. At such temperatures the nuclear reactions will affect mainly the light elements. If they are energy-generating reactions they will diminish the rest-mass of the participating nuclei, as in the deuteron-building reaction of § 24; it is easy to see that if a proton reacts with any of the other light atoms whose masses are given in Table III, the combined masses of the reactants will decrease, and particularly so if for one or both of the products the value of $A-A'$ is small, as it is for He^4 (and also C^{12} and O^{16}). Conversely, reactions in which He^4 is one of the reactants and H^1 is one of the products (§ 17) will increase the rest-mass and absorb energy (§ 25). Helium-building from protons (alone or with other light nuclei) is the most productive and, after deuteron-building, the simplest energy-generating process.

The building of nuclei much heavier than helium is possible only at temperatures far exceeding those at which helium-building can occur. Unless it should appear that the temperatures of the central regions of the Sun and stars are to be reckoned in many thousands of millions of degrees (as Milne has urged), one must conclude either that the heavier nuclei were part of the original creation, or that they were formed at these ultra-high temperatures from lighter nuclei, perhaps hydrogen, in some primitive state of the universe before the stars were born.

In seeking the source of the Sun's energy, therefore, it is necessary to consider in detail what nuclear reactions will proceed, and at what rate, in a gas composed of hot crushed matter containing the light elements in any assumed proportions; the presence of heavier elements will not essentially affect the problem, though their additional mass will reduce the average calorific value.

30. *Atomic Mechanics.*—To calculate the rate of a nuclear reaction in such a gas, one must know the mechanics of nuclei; such knowledge is at present based on the results of experiments on nuclear reactions, and in any case must be checked by experiment.

Newton's laws of mechanics and of gravitation "explain" almost perfectly the motions within the solar system, given a knowledge of the system at one instant; but they do not require the planetary orbits to have their actual mean radii, showing the regularity described by Bode's law.

Likewise if we consider the structure of an atom in the light of Bohr's simplified but valuable orbital model, we find a definiteness in the radii and disposition of the electronic orbits which is not imposed by the Newtonian mechanics and the Maxwellian electromagnetic theory; this definiteness is "explained" by additional "quantum" conditions, shown later by Schrödinger to be connected with wave properties possessed by material particles. These wave properties enable the energy levels of the atom to be calculated, in marvellous agreement with observations of atomic spectra (and many other atomic properties); the spectra give direct evidence of the *differences* between the energy levels.

31. *Nuclear Mechanics.*—Atomic nuclei, on a still smaller scale, also manifest energy levels and can be "explained" by the wave mechanics. But although nuclear structure has this "quantum" definiteness, some things are less absolute, in the wave mechanics of the nuclei, than in the classical mechanics of such particles. In particular, a proton or α-particle has some chance of entering a nucleus even though its initial kinetic energy is insufficient to carry it to the small distance from the nuclear centre, at which the electrostatic repulsion is overcome by attractive forces of another kind. During the approach against the repulsion, the kinetic energy is steadily transformed into potential energy. The potential energy thus acquired by a charge which, coming from infinity, just reaches the point where the repulsion ceases, may be called the potential barrier surrounding the nucleus.

One can illustrate this barrier, in a two-dimensional model (fig. 2), by a ring-wall surrounding a cup-like depression or potential "well" which contains the constituent particles of the nucleus, namely, protons and neutrons, some of them grouped into α-particles. The ring-wall slopes away outside to a level plane. To roll a small ball into the well from far outside, we must give it enough energy E to surmount the ring-wall and join the particles already within. Similarly, if a ball is projected from the inside to the outside, it must mount the wall, and after its descent outside it will have kinetic energy at least equal to E.

In the case of heavy nuclei, the "height" of the potential "well" can be inferred from the scattering of particles projected towards, but not entering, the nucleus. But the α-particles ejected by radioactive nuclei have less energy than would correspond to their "rolling down" the outside of the potential well. This was "explained" by Gamow *,

* A. Gamow, *Zs. f. Phys.*, 51, 204, 1928; 52, 510, 1928, and (with F. A. Houtermans) 52, 496, 1928.

and by Gurney and Condon *, using the wave picture of particles. If a *wave* impinges on a barrier which is not a perfect reflector, a very small part of it is transmitted through the barrier; a nucleus impinging on the barrier, if viewed as a *particle*, must either be reflected as a whole or penetrate as a whole, but if viewed as a *wave*, the slight *amount* of its penetration is interpreted as a slight *chance* of penetration of the whole nucleus, even though its energy is insufficient to *surmount* the barrier; it may be said to pass *through* the barrier.

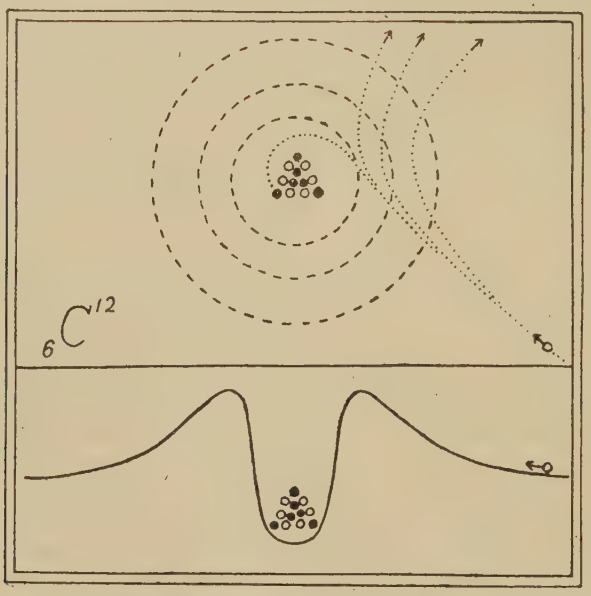

FIG. 2.—Above, *a carbon nucleus (diagrammatic) and its field of electrostatic force (repulsive, on a proton or other positive charge), represented by broken lines; within the innermost circle the force is attractive instead of repulsive. The dotted lines are the paths of a proton (represented, as in fig. 1, by a simple circle) projected towards the nucleus with different speeds. On the "classical" view, the proton can enter the nucleus only if its speed is sufficient to carry it up to the innermost circle; on the "wave" view, the proton has a (very small) chance of entry even if its speed is less than this.* Below, *the repulsive field is illustrated by a barrier which the proton has to surmount in order to enter the "well" containing the nucleus.*

This interpretation can be applied either way, to the exit of a particle from the nucleus (*e.g.* α-rays from radioactive nuclei), or to the entry of a proton or α-particle. The nucleus may retain an incoming particle, only adjusting its energy by the emission of γ-rays; or it may lose an electron (by the transformation of one of its neutrons into a proton, or *vice versa*); or it may redivide, as in Rutherford's first reaction (§ 17).

Referring to our two-dimensional model of the nucleus, one can imagine a particle shot so energetically towards the ring-wall as to mount it, force its way through the particles within and escape on the other side; or perhaps instead to eject one of the particles already inside. The wave picture replaces the surmounting of the wall by occasional penetrations through it, involving far less energy.

Evidently there is much scope for complexity in nuclear encounters and reactions, and experiments confirm this expectation; for given types of nuclei, some speeds of encounter are more favourable than others. Reactions in which a compound nucleus, formed from two encountering nuclei, redivides into two different parts, as in § 17, are far more probable than those in which only a β- or γ-ray escapes from the compound

* R. W. Gurney and E. U. Condon, *Phys. Rev.*, **33**, 127, 1929.

nucleus. The calculation of the probabilities and rates of nuclear reaction in crushed matter at a given temperature, first attempted by Atkinson and Houtermans * (1929), is too elaborate to be described here. I must confine myself to a brief outline of the *results*, which have been developed most fully by Bethe (1939).†

32. *Deuteron Formation in Hot Hydrogen.*—The most primitive of all nuclear reactions is deuteron formation from protons. If, at creation, the universe consisted of pure hydrogen, deuteron-building must have been the first stage in the evolution of the heavier elements. However, the calculation of the rate of this process in hot hydrogen is a pure theoretical problem, in no way dependent on speculations as to the distant past. Bethe and Critchfield ‡ have made this calculation, which is based on experimental data combined with theory, *i.e.* the Gamow-Teller § theory of electron (β-ray) emission from nuclei, which they accept on "strong evidence"; at some points in the calculation simplifying assumptions are made to facilitate the mathematics, so that the final results are uncertain by a moderate factor.

Their expression for the number of deuterons formed per gram per second in a gas of (absolute) temperature T and density ρ (grams/cm.^{3}), of which a fraction f (by weight) is hydrogen, is

$$0{\cdot}95 \times 10^7 \rho f^2 \tau^2 e^{-\tau},$$

where

$$\tau = 3{\cdot}38 \times 10^3 / \sqrt[3]{T}.$$

The factor $\tau^2 e^{-\tau}$, which determines the temperature-dependence of the reaction, is here tabulated (directly, and also in the form of inverse powers of 10), for values of T from 1 to 100 million degrees; it shows that at a million degrees the factor $\tau^2 e^{-\tau}$ is only (so to speak) 1 part in 2·4 million million, whereas at 5 million degrees it is 1 per million, and at 20 million degrees 6 per ten thousand. Thus, as anticipated (by very crude methods) in § 26, the protons do not react to any appreciable extent until the temperature attains some millions of degrees.

$10^6 \times$	1	5	10	15	20	30	40	50	100
	33·8	19·79	15·69	13·71	12·45	10·88	9·88	9·17	7·28
$=$	$2{\cdot}4 \times 10^{-12}$	$1{\cdot}0 \times 10^{-6}$	$3{\cdot}8 \times 10^{-5}$	$2{\cdot}1 \times 10^{-4}$	$6{\cdot}1 \times 10^{-4}$	$2{\cdot}2 \times 10^{-3}$	$5{\cdot}0 \times 10^{-3}$	$8{\cdot}9 \times 10^{-3}$	$3{\cdot}6 \times 10^{-2}$
$=$	$10^{-11{\cdot}61}$	$10^{-5{\cdot}99}$	$10^{-4{\cdot}42}$	$10^{-3{\cdot}68}$	$10^{-3{\cdot}22}$	$10^{-2{\cdot}65}$	$10^{-2{\cdot}30}$	$10^{-2{\cdot}05}$	$10^{-1{\cdot}44}$

The deuteron formation will be followed by the reaction

$$_1H^1 + {}_1H^2 = {}_2He^3 + \gamma.$$

Bethe and Critchfield estimate that this reaction is 10^{18} times as probable as the proton-proton reaction, because the latter involves β-ray emission, a far slower process than the emission of γ-rays or (as in § 17) heavy particles. Hence each deuteron formed will have an extremely short life; in equilibrium there will be only about 1 deuteron to 10^{18} protons. Consequently, though laboratory experiments show that deuterons easily react with one another, as in the equation

$$_1H^2 + {}_1H^2 = {}_1H^3 + {}_1H^1,$$

this would very rarely happen in the hot hydrogen gas because deuterons would seldom meet.

Bethe and Critchfield suggest that in a star the He^3 nucleus would rapidly be con-

* R. d'E. Atkinson and F. G. Houtermans, *Zs. f. Phys.*, **54**, 656, 1929; see also R. d'E. Atkinson, *Ap. J.*, **73**, 250, 308, 1931.

† H. A. Bethe, *Phys. Rev.*, **55**, 434, 1939 (see § 2 for the reaction-rate formula); *Ap. J.*, **92**, 118, 1940; also H. A. Bethe and R. E. Marshak, *Rep. Prog. Phys.*, **6**, 1, 1940. See also C. F. v. Weizsäcker, *Phys. Zs.*, 38, 176, 1937.

‡ H. A. Bethe and C. L. Critchfield, *Phys. Rev.*, **54**, 248, 862, 1938.

§ G. Gamow and E. Teller, *Phys. Rev.*, **49**, 895, 1936; **53**, 608, 1938.

verted into He^4 by the following chain of reactions * (which can proceed as soon as any He^4 has already been formed):—

$$
\begin{aligned}
{}_2He^3 + {}_2He^4 &= {}_4Be^7 + \gamma, \\
{}_4Be^7 &= {}_3Li^7 + {}_1e^0, \\
{}_3Li^7 + {}_1H^1 &= 2\,{}_2He^4.
\end{aligned}
$$

As these are more rapid than the deuteron formation, the latter would govern the rate of conversion of protons, by the 5-fold reaction, into α-particles. The energy gained per α-particle formed is $(4 \times 1{\cdot}00813) - 4{\cdot}00386$ atomic mass units, or $0{\cdot}02866\ u_m$ grams (§§ 5, 23, 24, and Table III), or $4{\cdot}3 \times 10^{-5}$ ergs. Hence ϵ, the rate of generation of energy per gram, is

$$410\ \rho f^2 \tau^2 e^{-\tau} \text{ ergs.}$$

Using the values of $\tau^2 e^{-\tau}$ in the preceding table, we get the following values of $\epsilon/\rho f^2$ at the temperatures there considered:—

$T = 10^6 \times$	1	5	10	15	20	30	40	50	100
$\epsilon/\rho f^2 =$	10^{-9}	4×10^{-4}	0·015	0·086	0·25	0·90	2·0	3·6	15

Thus at 20 million degrees, if ρf^2 were 10, ϵ would be 2·5 ergs per gram per second, comparable with the average rate of energy generation for the Sun. Eddington's studies of stellar structure (§ 37) led him to conclude (before the calculation of nuclear reaction rates became possible) that the central temperature and density of the Sun (T_c, ρ_c) are about 20 million degrees and 76 respectively, and that f, the proportion of hydrogen, is 0·35 (or 35 per cent.); in this case $\rho f^2 = 10$, and the above table gives $\epsilon = \epsilon_c = 2{\cdot}5$ at the centre, *if no other reactions contribute to* ϵ.

As we proceed outwards from the centre, T and ρ decrease, and ϵ (due to this particular process) decreases much more rapidly. The energy generation must thus be confined to the central hot regions, and the observed average rate $\bar{\epsilon}$ $(= 1{\cdot}9)$ must correspond to a higher rate in the region actually concerned.

Bethe and Critchfield suggest that helium-building by deuteron formation makes an appreciable, but not the main, contribution to $\bar{\epsilon}$ for the Sun, and that in less massive stars, for which T_c and $\bar{\epsilon}$ are smaller, it is the chief source of energy.

For heavier stars $\bar{\epsilon}$ increases rapidly with the mass, whereas the central temperature T_c, as calculated on Eddington's theory, increases only slightly. This implies that in heavy stars the energy generation is due to a process for which ϵ varies as a high power of T. In the process here considered, ϵ varies approximately † as $T^{3{\cdot}5}$, for values of T near 20 million degrees. Hence it is necessary to seek another energy-producing reaction which can operate in the Sun, and which becomes predominant in the heavier stars.

33. *Exhaustible Reactions.*—Bethe has made a detailed examination of the nuclear reactions likely to be of importance in a mixture of all the elements at temperatures up to 20 or 30 million degrees; only the lighter elements (Tables I and III) need consideration, as the greater repulsion between the nuclear charges of the heavier elements reduces their probability of reaction. He gives reasons for believing that no element heavier than helium can be built up in ordinary stars. Hence the existing elements must have existed during the period when the stars were cooler and larger than now.

The argument of § 32 seems to render it unlikely that the stars, in their early cool state, would include many deuterons, though deuterons exist in terrestrial matter. In any case, as soon as the central temperature approaches a million degrees, they would combine rapidly with protons to form He^3, before the production of new deuterons

* The second of these is a radioactive process, with a half-life of 43 days (*cf.* Table II).

† If ϵ varies approximately as T^n, then $n = d \log \epsilon / d \log T = \frac{1}{3}(\tau - 2)$, if ϵ depends on T only through the function $\tau^2 e^{-\tau}$, in which $\tau \propto T^{-\frac{1}{3}}$.

became appreciable, as at higher temperatures (§ 32). Thus the original deuterons would quickly be "burnt up," and provide no long-enduring source of energy.

Three other light elements also react rather readily with protons, namely, lithium, beryllium and boron, as follows:—

$$_3Li^6 + {}_1H^1 = {}_2He^3 + {}_2He^4, \qquad {}_3Li^7 + {}_1H^1 = 2\,{}_2He^4,$$
$$_4Be^9 + {}_1H^1 = {}_3Li^6 + {}_2He^4,$$
$$_5B^{10} + {}_1H^1 = {}_6C^{11} + \gamma, \qquad {}_5B^{11} + {}_1H^1 = 3\,{}_2He^4.$$

Calculation shows that all these reactions, save the one involving $_5B^{10}$, occur readily at temperatures ranging from 3 to 7 million degrees. The B^{10} reaction is slower, because the proton is captured and the compound nucleus does not redivide (§ 31); this reaction proceeds readily only when the temperature approaches 20 million degrees.*

These processes will all supply energy to a star in the earlier stages of its heating by contraction, but the supply will be short-lived because one constituent in the reactions is not renewed. Naturally the elements lithium, beryllium and boron will disappear only in the regions where the temperature is sufficiently high: this region will spread outwards from the centre as the star contracts. If the stellar matter is appreciably mixed by convection, the outer layers also will gradually lose these elements; and it is an interesting fact that in stellar atmospheres, and also in meteorites and in the Earth's crust, these three elements are far less abundant than any of the other elements in Table I.

These exhaustible reactions with protons differ completely from the deuteron-building reaction in that, however abundant the proton supply, they cease when the other reacting constituent is used up.

It might be thought that helium should likewise react with protons and be exhausted, though the abundant helium present in stars forbids this view. It fails to happen because Li^5 and He^5 do not exist: a compound nucleus formed from He^4 and H^1 will not hold together.

34. *The Carbon Cycle.*—The lightest elements after *H* and *He*, when all the *Li*, *Be* and *B* are exhausted, are carbon and nitrogen, each with two stable isotopes (Table I). These four nuclei can all capture a proton; in two cases the resulting nucleus is unstable (radioactive). The reactions are as follows:—

$$(1)\ {}_6C^{12} + {}_1H^1 = {}_7N^{13} + \gamma \qquad (2)\ {}_7N^{13} = {}_6C^{13} + {}_1e^0$$
$$(3)\ {}_6C^{13} + {}_1H^1 = {}_7N^{14} + \gamma \qquad (4)\ {}_7N^{14} + {}_1H^1 = {}_8O^{15} + \gamma$$
$$(5)\ {}_8O^{15} = {}_7N^{15} + {}_1e^0 \qquad (6)\ {}_7N^{15} + {}_1H^1 = {}_8O^{16} + \gamma$$
$$(7)\ {}_7N^{15} + {}_1H^1 = {}_6C^{12} + {}_2He^4$$

It is evident that the equations (1) to (5), together with (6) and (7), constitute not merely a catalogue of possible reactions, but also, if (6) and (7) are regarded as alternative possibilities (as they are), a succession of changes each one of which leads to the next. If the reactions (1) to (5) are followed by (6), the successive capture of four protons has built up an oxygen nucleus ($_8O^{16}$) from a carbon nucleus ($_6C^{12}$), with the emission of three γ-rays and two positrons. The energy released (*cf.* Table III) is the equivalent of $10^{-5} \times (386 \times 4 + 813 - 16 \times O) = 3638 \times 10^{-5}$ atomic units of mass. If (1) to (5) are followed by (7), the original carbon nucleus is restored and the net result is that a helium nucleus is built from four protons, with the emission of three γ-rays and two positrons; the energy released is equivalent to $10^{-5}(4 \times 813 - 386) = 2866 \times 10^{-5}$ atomic units of mass.

The reaction (7) is found to be a million times as probable as (6), so that only one carbon nucleus out of a million will be lost by the reactions (1) to (5) followed by (6). In all the other cases the carbon nucleus is restored and can take part in a new cycle of the same reactions (fig. 3).

Such a cycle, in which one constituent is ultimately restored unchanged, is called

* The $_6C^{11}$ nucleus formed in this reaction is unstable (Table II), and in 21 minutes emits a positron and becomes $_5B^{11}$, which reacts with a proton as above.

catalytic in ordinary chemistry; this constituent merely *assists* in the building up of helium from protons. From this standpoint (1) is the natural beginning of the cycle, though so far as the restoration of the catalyst is concerned, the cycle might equally well be considered as beginning with (3), (4) or (7).

35. *The Reaction Rates in the Carbon Cycle.*—All the reactions in the carbon cycle have been observed in the laboratory during the years 1938–1940, and their reaction

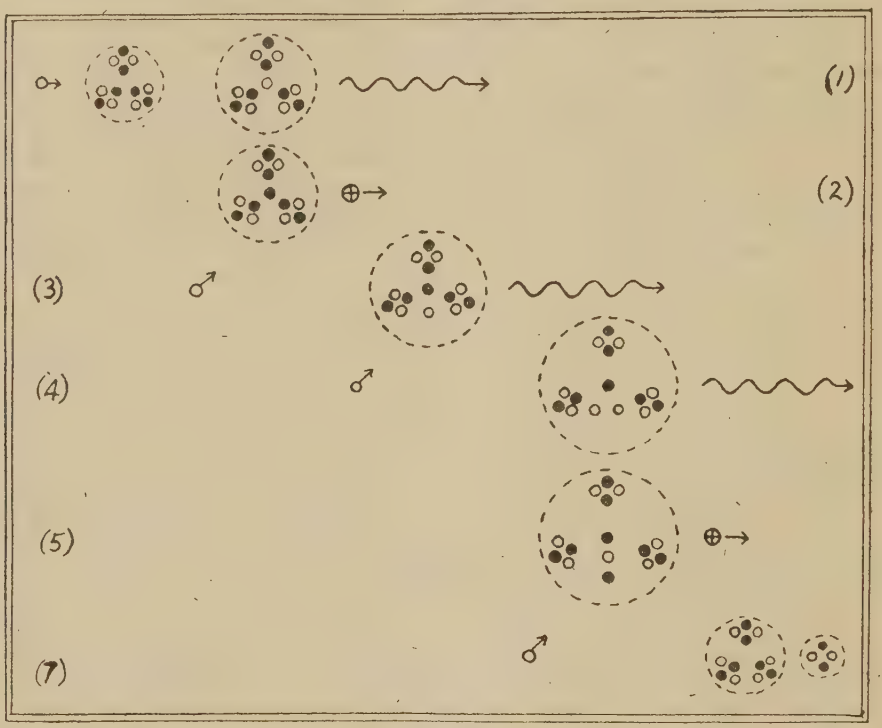

FIG. 3.—*Diagrammatic representation of the carbon cycle of reactions. Protons, neutrons and nuclei are represented as in fig.* 1 *(lower part); circles containing the* + *sign represent positive electrons, and the wavy lines represent a photon of gamma radiation. Each horizontal section of the diagram represents one of the reactions* (1) *to* (5) *and* (7) *of* § 34, *the uppermost being* (1) *and the lowermost* (7). *In the reactions* (1), (3), (4) *and* (7) *the nuclear mass increases steadily from* 12 *to* 16, *but in* (7) *the compound nucleus of mass* 16 *breaks up into a carbon nucleus (mass* 12, *as originally in* (1)) *and a helium nucleus (mass* 4). *Except in the last proton capture, where the compound nucleus divides, the energy is adjusted by gamma radiation. But in* (2) *and* (5) *the nucleus formed in the preceding reaction is unstable, and a proton in the nucleus is converted into a neutron by the emission of a positive electron.*

probabilities can be estimated from the experiments. Under the conditions (T_c, ρ_c, f) at the centre of the Sun, as inferred by Eddington (§ 32), the average intervals between the successive reactions involving any one catalytic nucleus (C or N) are as follows, according to Bethe, who states that the times may easily be wrong by a factor 3 either way (this uncertainty does not affect the two *brief* intervals, which are the observed half-lives (Table II) of the radioactive nuclei N^{13} and O^{15}):—

$2\frac{1}{2}$ million years	...	$H^1 + C^{12} = N^{13} + \gamma$
9·9 minutes ...	...	$N^{13} = C^{13} + e^+$
50,000 years ...	...	$H^1 + C^{13} = N^{14} + \gamma$
4 million years	...	$H^1 + N^{14} = O^{15} + \gamma$
2·1 minutes ...	...	$O^{15} = N^{15} + e^+$
20 years ...	...	$H^1 + N^{15} = C^{12} + He^4$

Thus the time required for the complete cycle of reactions per catalytic nucleus, at the Sun's centre *, is about 6½ million years. In order that the rate of reaction shall suffice to give the observed energy supply, the number of carbon and nitrogen nuclei, "working" at this rate, must have a definite value; carbon and nitrogen must each contribute roughly ½ per cent. (by mass) of the central solar matter. This agrees reasonably well with their surface abundance.

The reaction probability for N^{15} is 2×10^5 times as great as that for N^{14}, so that the abundance ratio for N^{14} to N^{15} at the centre of the Sun should be 2×10^5; on the Earth this ratio is only 260 to 1. Bethe suggests that the difference may be due to separation of the Earth from the Sun when the Sun was cooler than now, before the onset of the carbon cycle had led to reaction-equilibrium between N^{14} and N^{15}. This fits in also with the existence of the observed amounts of *Li*, *Be* and *B* in terrestrial matter (§ 33).

36. *Proton Reactions with Oxygen and heavier Nuclei.*—Bethe has also calculated the reaction intervals, for the central solar conditions already considered, for proton-capture by oxygen and heavier nuclei. His estimates, though perhaps rough, imply that such reactions can have little importance for the Sun's energy generation. For O^{16} the reaction interval is 10^{12} years, for F^{19} it is 3×10^7 years, for Ne^{22} it is 2×10^{13} years, and for heavier nuclei it is still greater. The rate of energy generation due to such reactions is altogether inferior to that for the carbon cycle, and the reactions are also exhaustible.

37. *The Internal Constitution of a Star.*—As Eddington showed, much can be learnt of the internal constitution of the stars without knowing exactly how or where the observed energy output is generated. From 1916 onwards, in successive stages, he traced out the main features of the problem. His brilliant book on this subject † describes the progress made up to 1926. He pictures the stars as two bodies superposed: a material body, in dynamical equilibrium, and a body of radiation, not in equilibrium; gravitation holds the matter together, but the radiation slowly struggles outwards, hindered by the opacity of the matter. The thermal conditions adjust themselves so that at each level the radiative outflow of energy (to which convection makes only a minor addition) carries upwards all the energy generated below that level. Calculations were made for two alternative distributions of energy generation; in one (the point-source stellar model) all the energy is supposed to be produced at the centre; in the other model the energy generation is less concentrated, being such that ϵ_r, the average production per gram within any radius r is inversely proportional to the opacity k, or, with the adopted law $k \propto \rho/T^{3.5}$, $\epsilon_r \propto T^{3.5}/\rho$.

Beyond a moderate depth the matter is in the "crushed" form (§§ 27, 28), and behaves like a perfect gas, with an average mass per particle ‡ ($\bar{A}$, § 28) equal to 2 or less. The equations of mechanical equilibrium and thermal outflow, together with the equation of state of the gas, determine the distribution of temperature, density and pressure for a given chemical composition; the influence of the latter depends mainly on the proportion of hydrogen.

In 1932 Eddington § much increased his estimate of the hydrogen content, partly

* If the density of the hydrogen at the centre of the Sun ($f\rho_c$) differs from the assumed value (0.35×76 or 2.7) the above reaction times would be altered in the inverse ratio ($\propto 1/f\rho_c$). A change in the assumed temperature would alter the *rate* of the reaction cycle in proportion to $\tau^2 e^{-\tau}$ (§ 32), where for the carbon cycle $\tau = 1.52 \times 10^4/\sqrt[3]{T}$. At 21 million degrees the rate varies approximately as $T^{17.4}$, and at 25.7 million degrees as $T^{16.5}$; thus the temperature dependence is much greater than that of the proton-proton reaction of § 32.

† *The Internal Constitution of the Stars* (1926). See also S. Rosseland, *Theoretical Astrophysics*, 1936, B. Strömgren, *Ergeb. d. exakt. Nat.-Wiss.*, **16**, 465, 1937, and S. Chandrasekhar, *An Introduction to the Study of Stellar Structure* (1939).

‡ Or mean molecular weight.

§ *M.N.*, **92**, 471, 1932; and also, independently, B. Strömgren, *Zs. f. Ap.*, **4**, 118, 1932; **7**, 122, 1933.

because Russell * had shown that hydrogen is very abundant in stellar atmospheres, and partly to bring his inferred value of the *opacity* of stellar matter into better accord with physical theory. Since then Morse † has improved the calculation of the opacity, particularly in regard to what Eddington calls the "guillotine" factor ‡, which depends on the chemical composition as well as on the temperature and density.

Eddington's 1932 revision of his theory reduced his estimates of the central temperature T_c from 40 to 20 million degrees, without altering the estimate (§ 32) of the density ρ_c. The estimated value of $\bar{A}$ was reduced from 2·1 to 1·06. Cowling § made similar

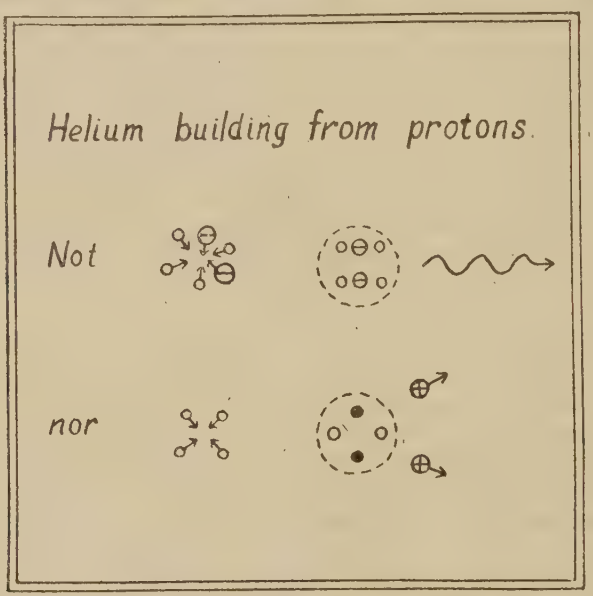

FIG. 4.—*The building of helium nuclei from protons is achieved by the step-by-step process shown diagrammatically in fig.* 3. *When the structure of the helium nucleus was supposed to be as shown in the upper part of fig.* 1, *it seemed that to form such a nucleus it was necessary* (*fig.* 4, *upper part*) *for four protons and two negative electrons to come together all at once—a most improbable event. A less improbable but still extremely unlikely method is by the coming together of four protons* (*fig.* 4, *lower part*) *with the emission of two positive electrons.*

calculations, using the point-source model; he found the same value of T_c, but his estimate of ρ_c was only 51.

38. *Eddington's Discussion of Energy Generation.*—The most important change in the theory of a star has come, however, from the development of nuclear chemistry. In 1926 Eddington considered two main possible sources of stellar energy; one was the mutual annihilation of protons with electrons, each pair dissolving into radiation. The other was the building up of helium nuclei from protons; this he thought was the more probable, although (he remarked), "We should say that the assemblage of 4 hydrogen nuclei and 2 electrons to form the helium atom was impossible if we did not know that it had occurred" (fig. 4). We can to-day see (fig. 3) how simply Nature avoids this truly formidable situation. As to the "annihilation" of protons and electrons, it now seems as if, at worst, only a neutron would result, though the annihilation of negative

* H. N. Russell, *Ap. J.*, **70**, 11, 1929; see also *Nature*, **148**, 647, 1941.

† P. M. Morse, *Ap. J.*, **92**, 27, 1940.

‡ Must this gruesome metaphor, perpetuating the memory of the regrettable M. Guillotine, persist for ever in astronomical literature? Why not "(opacity) cut-off factor"?

§ T. G. Cowling, *M.N.*, **96**, 42, 1938.

electrons by positive ones (then undiscovered) is a common occurrence, of no primary importance for stellar theory.

It remains to add that in 1938 Cowling * removed a difficulty raised by Eddington, who feared that a high-temperature dependence of the rate of energy generation inside a star would involve instability.

39. *Recent Stellar Models.*—G. Blanch, A. N. Lowan, R. E. Marshak and H. A. Bethe † have made a new calculation of the internal state of the Sun, assuming all the energy generation to occur within a central core, in which the equilibrium is convective (with $\rho \propto T^{3/2}$), instead of radiative as throughout the remainder of the volume. They assume a constant chemical composition—a proportion f of hydrogen, the rest being the mixture of elements inferred for the surface layer of the Sun by Russell. The average mass per particle, $\bar{A}$, was also taken to be constant, and exactly equal to 1. Attention was paid to the cut-off factor in calculating the opacity, though without taking detailed account of the influence, on $\bar{A}$ and on the opacity, of the radial non-uniformity in the degree of ionization.

The hydrogen content f was *determined* by the condition of fit at the boundary of the convective core; the result agreed with Eddington's value (35 per cent.); the core contained a ninth of the Sun's mass in an eighth of the Sun's radius; the values found for T_c and ρ_c were 25·7 million degrees and 110, somewhat higher than Eddington's values.

From the temperature and density distribution thus found they *calculated* the energy generation, assuming it to be due solely to the carbon cycle (with 1 per cent. of carbon plus nitrogen). With satisfaction they found that all but $2\frac{1}{2}$ per cent. of the energy *would* on this assumption be generated within the convective core; but the calculated total generation was 100 times the observed outflow. They conclude: "We do not regard the discrepancy" . . . "as any argument against the carbon cycle as a source of energy of main-sequence stars. These uncertainties appear insignificant when the carbon cycle is compared with other nuclear reactions. All other reactions (except possibly the proton-proton reaction for less luminous stars of the main sequence) are excluded by much larger factors than 100." Finally, they say it is almost certain that an improved treatment of the cut-off factor, a suitable admixture of helium, and other reasonable amendments, "will remove the discrepancy entirely."

Still more recently they have made a similar but improved calculation for Sirius.

40. This concludes my outline of the recent advances in the theory of energy generation within the Sun. Necessarily it has omitted much that appears, for example, in the brilliant and amusing popular account ‡ of the subject by Gamow, who includes in his discussion the giant and white dwarf stars, and many other aspects of the universe and its evolution.

I have tried to show that though some discrepancies and difficulties still remain in the theory of the Sun's internal state, the progress of nuclear physics appears to have brought us within sight of a solution of the problem which seemed so inscrutable to Kelvin, and so baffling even in 1926 to Eddington. The outcome will be a "model" of the Sun (and similar stars) substantially, though not completely, based on astrophysical observations and on physical theory founded on laboratory experiments; it will be a possible and self-consistent solution. There remains the question, Is it the actual and only possible solution, or can Milne be right in urging a quite different solution as possible and actual? I think the burden of proof, which seems to me no light one, must rest on him.

Finally, the Helmholtz contraction hypothesis of stellar evolution and energy supply is not discarded, but only relegated to a transient early phase of stellar history. If the

* T. G. Cowling, *M.N.*, **96**, 42, 1938.

† *Ap. J.*, **94**, 37, 1941; see also *Bull. Amer. Phys. Soc.*, **17**, 7, 1942.

‡ *The Birth and Death of the Sun*, 1941.

stars were ever cool extended spheres of gas, broken up from a continuum by the process of gravitational instability studied by Jeans, they became hot inside by their contraction within a few million years. This raised the temperature of the central furnace to the value necessary to initiate proton "combustion" into helium; thus, as I have said elsewhere *, the solar engine was ignited by compression, like some internal combustion engines.

* Kelvin Lecture, *J. Inst. Elec. Eng.*, **88**, 400, 1941.

General References

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